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ABSTRACT

Water pollution techniques and practices, including data analysis, interpretation and display are described in this book intended primarily for the biologist inexperienced in this work, and for sanitary engineers, chemists, and water pollution control administrators. The characteristics of aquatic environments, their biota, and the effects of various pollutants upon them are discussed and illustrated by examples of field investigations involving organic wastes, silts, toxic wastes, mine drainages, eutrophication, and radioactive wastes. Separate chapters describe the biology of water supplies and sewage treatment. The nature and control of biological nuisances such as slimes are discussed. Bibliography. (Author/AL)

THE PRACTICE OF WATER POLLUTION BIOLOGY

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

THE PRACTICE OF WATER POLLUTION BIOLOGY

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UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DIVISION OF TECHNICAL SUPPORT
1969

FOREWORD

PROTECTION and enhancement of the Nation's waters in the face of continued pressures of population and industrial growth, urbanization, and technological change is a major task and challenge confronting us. A key to our success will be the extent to which we can define and understand the quality and behavior of the aquatic environment. The study of life in water is an essential part of that understanding. Determination of the effects of pollution upon the aquatic biota uses, and recognition and control of the plants and animals that create nuisances or costly problems are critical elements in the multifaceted scientific effort needed. This book, which is devoted to a comprehensive discussion of problem investigation and problem solving through the techniques of aquatic biology, will be a valuable contribution in assisting those who are involved in the applied aspects of water pollution control.

David D. Dominick

DAVID D. DOMINICK, *Commissioner*
Federal Water Pollution Control Administration

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PREFACE

TO fulfill a need that has become apparent, this book presents some practical water pollution biological field investigative techniques and practices, procedures to solve problems, data analyses, interpretation and display, and the development and writing of the investigative report. It is written principally for the biologist inexperienced in these activities, and for sanitary engineers, chemists, attorneys, water pollution control administrators, and others who are interested in broadening their understanding of this discipline.

The book considers the many aquatic environments, their biotic constituents, and the effects of various pollutants upon them. Field investigations that include forming the study objectives, planning the field study, station selection, sample collection and examination, data analyses and interpretation, and reporting the results are described. Individual water quality constituents that affect the aquatic environment are discussed. Examples of field studies on specific water pollution problems are given with the collected data presented in many graphic variations. The ability to present a clear, understandable concept to the viewer by different methods of displaying data is evaluated. Examples of field investigations, with which the author has been involved, including data collection, analyses, interpretation and display are given for organic wastes, silts, toxic wastes, acid mine drainages, eutrophication, and radioactive wastes. Investigations in marine waters are discussed. Separate chapters detail the biology of municipal water supplies and sewage treatment. Biological nuisances and slimes are discussed, as well as their control.

In presenting the book's contents, over 20 years of biological field investigative experience are represented in the described field and laboratory methods, report writing, and data display. Methodology modifications presented may be of value to other professional biologists. Because the results from most problem solving investigations must be presented to the lay public to engage their support for remedial actions, reporting and data display must be clear and readily understandable. Clearness and understandability have been goals of this book.

Washington, D.C.
September, 1969

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Acknowledgments are given Mr. Carl Shadix, FWPCA, for Figure 1; Milo Churchill, Tennessee Valley Authority, Figure 8; Miss Lois Best, FWPCA, Figure 11; Horn Photo, Clatskanie, Oreg., courtesy of Earl N. Kari, FWPCA, Figure 74; Carl A. Werner, District Engineer, California Department of Water Resources, Figures 79 and 80; Aquatic Controls Corporation, Hartland, Wis., figure 81; and Dr. John E. Gallagher, Amchem Products, Ambler, Pa., figure 85.

The assistance of past and present coworkers from the many disciplines within the National Field Investigations Center, FWPCA, was an essential contributing factor to the gathering of information and the development of studies presented here. Team effort has become a byword of the Center and the "team" included engineers, chemists, biologists, microbiologists, technicians, secretaries, and administrators.

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STAGE SETTING

WATER:

A necessity for life
A transporter of disease
A sustainer of navigation
A coolant, cleanser, diluent
A medium for recreational pursuits
A resource with food for populations
A power source to harness and control
A source of tranquil, aesthetic enjoyment
A refuge for biological pests and nuisances
A defiled purveyor of civilization's wastes

Water means different things to different people. A particular definition depends in large measure on the personal uses to which water is put by the definer. In this book the concern is not so much with specific water uses as it is with water quality and aquatic life, and the investigation of it.

A section in the National Technical Advisory Committee on Water Quality publication (Anon., 1968) states that, "It is not surprising that water has occupied an important position in the concerns of man. The fate of tribes and nations, cities and civilizations has been determined by drought and flood, by abundance or scarcity of water since the earliest days of mankind."

From the days of the earliest investigator it has been known that each water supports its particular life forms. As early as 1918 Henry Baldwin Ward wrote:

> "From the tiniest rivulet to the mightiest river one may find every possible intermediate stage, and between the swiftest mountain torrent and the most sluggish lowland stream there exists every intermediate gradation. Biologically considered, the torrent imposes on the development of life within its waters evident mechanical limitations which are not present in the slow-flowing streams. Ordinarily the

biological wealth of a stream varies inversely with its rate of flow, and anything which stops or checks the flow makes conditions more favorable for the development of life. Flowing waters are thinly inhabited and also present considerable difficulties to the student; hence they are relatively unexplored territory.

"Taken together lakes compose one-half the fresh water on the surface of the globe. They present an infinite variety of physical features in rocky, sandy, swampy margins, in steep and shallow shores, in regular and broken contours with no islands or many, with shallow water or depth that carry the bottom far below the level of the sea.

"They vary in the chemical character of the soil in the lake basin as well as in their banks and bed, in the degree of exposure to wind and sunshine, in the relative inflow and outflow in ratio to their volume, in their altitude as well as in geographic location. All of these and many other factors modify and control the types of living things and their abundance in the waters." (Ward and Whipple, 1918).

To continue the description of water quality in embellished terms, Mark Twain many years ago eulogized Lake Tahoe in this everlasting prose: [1]

> "In the early morning one watches the silent battle of dawn and darkness on the waters of Tahoe with a placid interest but when the shadows skulk away and one by one the hidden beauties of the shore unfold themselves in the full splendor of noon: When the smooth surface is belted like a rainbow with broad bars of blue and green and white, half the distance from circumference to center, when in the lazy summer afternoon, he lies in a boat far out to where the dead blue of the deep water begins and smokes the pipe of peace and idly winks at the distant crags and patches of snow from under his cap brim: When the boat drifts shoreward to the white water, and he lolls over the gunwale and gazes by the hour down through the crystal depths and notes the color of the pebbles and reviews the finny armies gliding in procession a hundred feet below: When at night he sees moon and stars, mountain ridges feathered with pines, jutting white capes, bold promontories, grand sweeps of rugged scenery topped with bald glimmering peaks, all magnificiently pictured in the polished mirror of the lake, in richest, softest detail the tranquil interest that was born with the morning deepens and deepens by sure degrees, till it culminates at last in resistless fascination."

Water quality affects man in his direct use of the water; it affects also the aquatic life that the water contains. Considering the latter, Shelford

[1] From "Lake Tahoe Water Quality Control Policy," June 1966, prepared by State of California, The Resources Agency, Lahontan Regional Water Quality Control Board.

(1918) chose to phrase these aspects as "conditions of existence." He stated that conditions of existence are of importance only insofar as they affect the life and death processes of organisms. Earlier, Forbes (1887) noted the complexity and interrelationship of organism community studies in water quality explorations with the words, "If one chooses to become acquainted with the black bass . . . he will learn but little if he limits himself to that species." Forbes further called attention to the close community of interest that exists among species with the reasoning that to exist a species birth rate must at least equal its death rate and that when a species is preyed upon by another it must produce regularly an excess of individuals for this destruction. Forbes went on to say that on the other hand the dependent species must not appropriate, on the average, any more than the excess of individuals upon which it preys. He argued that the common interest among species was promoted by the process of natural selection.

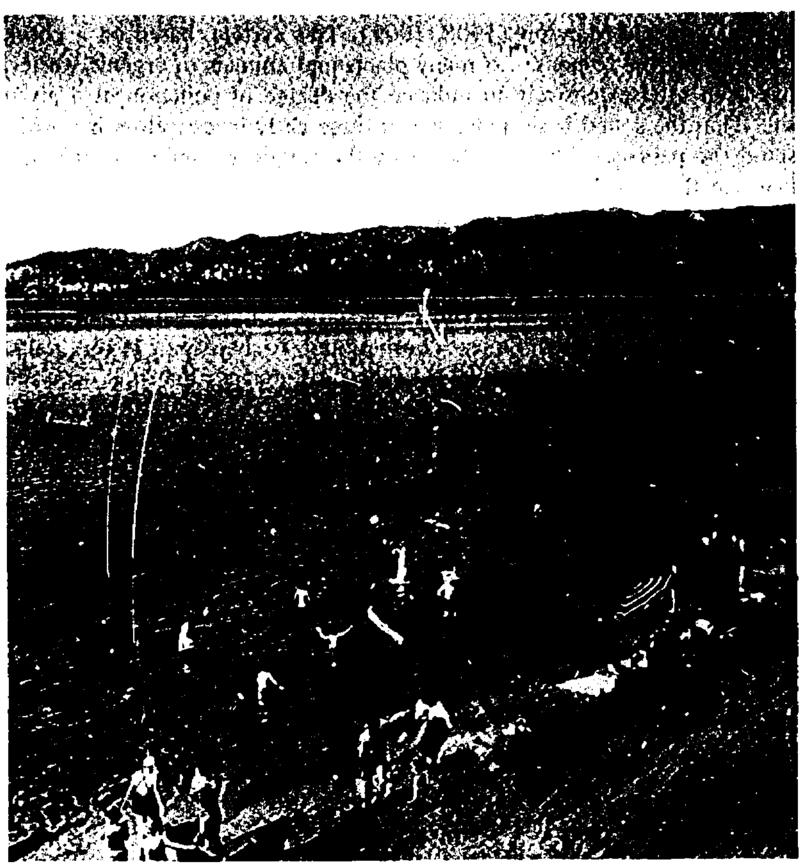

Figure 1. Lake Tahoe: A Jewel of the West

Aquatic biology, the subject of this discussion, is only one of many disciplines involved in water quality investigations. Other disciplines include chemistry, microbiology, engineering, hydrology, and geology.

The early chronicle of published biological effort began with Hassall in 1850 (1850, 1856) who noted the value of microscopic examination of water for the understanding of water problems. Sedgwick (1888) applied biological methods to water supply problems. Under his leadership the Massachusetts State Board of Health was the first agency in the United States to establish a systematic biological examination of water supplies. In 1889, Sedgwick collaborated with George W. Rafter to develop the Sedgwick-Rafter method of counting plankton. Whipple (1899) produced a treatise that, in 1948, was in its fourth edition and fifth printing; it has served through the years as an often-used reference in the water supply and water pollution field.

One of the first practical applications of biological data to the biological definition of water pollution was contained in the "saprobien system" of Kolkwitz and Marsson (1908, 1909). This system, based on a check list detailing the responses of many plants and animals to organic wastes, has been used extensively to indicate the degree of pollution at a given site. That the sound basic judgment of these early investigators has withstood the passage of time is shown by the frequent references currently made to their works.

The survey of the Illinois River by the Illinois Natural History Survey was one of the first studies that demonstrated clearly the biological effects of organic pollution; these studies were presented in a series of papers that provided much impetus and professional status to biological stream investigations in the United States (Forbes and Richardson, 1913, 1919; Forbes, 1928). Richardson (1921) described changes that had occurred in the bottom fauna of the Illinois River since 1913 resulting from increased movement of sewage pollution southward. Later, Richardson (1928) noted that ". . . the number of small bottom-dwelling species of the fresh waters of our distribution area that can be safely regarded as having even a fairly dependable individual index value in the present connection is surprisingly small; and even those few have been found in Illinois to be reliable as index species only when used with the greatest caution and when checking with other indicators."

Purdy (1916) demonstrated the value of certain organisms to indicate areas of pollution in the Potomac River receiving sewage discharges. The shallow flats of the Potomac River were found to be of great importance in the natural purification of organic wastes; sunlight and turbidity were observed to be prominent factors in the determination of oxygen levels and in waste purification processes. Weston and Turner (1917), Butterfield (1929), and Butterfield and Purdy (1931) reported other studies that demonstrated the effects of organic enrichment on streams, the sud-

den change in the biota after the introduction of the waste, and the progressive recovery of the biota downstream as the wastes were utilized.

Butcher (1932, 1940) studied the algae of rivers in England and noted that attached algal forms gave the most reliable indication of the suitability of the environment of an area for the support of aquatic life. In the United States, Lackey (1939, 1941a, 1942) investigated planktonic algae and noted their response to various pollutants. The work of Ellis (1937) on the detection and measurement of stream pollution, the effects of various wastes on stream environments, and the toxicity of various materials to fishes has served as a reference handbook and toxicity guide through many years.

Cognizance has been taken of the biotic community and the effect of pollution on the ecological relationships of aquatic organisms (Brinley, 1942; Bartsch, 1948). Bartsch and Churchill (1949) depicted the biotic response to stream pollution and related stream biota to zones of degradation, active decomposition, recovery, and clean water. Patrick (1949) described a healthy stream reach as one in which " . . . the biodynamic cycle is such that conditions are maintained which are capable of supporting a great variety of organisms," a semihealthy reach as one in which the ecology is somewhat disrupted but not destroyed, a polluted reach as one in which the balamce of life is upset, and a very polluted reach as one that is definitely toxic to plant and animal life. Patrick separated the biota into seven groups and illustrated specific group response to stream conditions with bar graphs. The number of species was used rather than the number of individuals. Fjerdingstad (1950) published an extensive list placing various algae and diatoms in zones or in ranges of stream zones similar to those of Kolkwitz and Marsson.

Epoch making water quality legislation in the Water Quality Act of 1965 that amended the Federal Water Pollution Control Act provided for the establishment of water quality standards for interstate (including coastal) waters.

Paragraph 3, section 10, of the Act reads as follows:

> "Standards of quality established pursuant to this subsection shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act. In establishing such standards the Secretary, the Hearing Board, or the appropraite state authority shall take into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses."

Subsequent to this legislation the Federal Water Pollution Control Administration issued guidelines for establishing water quality standards for interstate waters. These policy guidelines included such statements as "Water quality standards should be designed to 'enhance the quality of water.' . . . No standards of water quality will be approved which pro-

vide for the use of any stream or portion thereof for the sole or principal purpose of transporting wastes . . . Numerical values should be stated for such quality characteristics where such values are available and applicable. Where appropriate, biological bioassay parameters may be used. In the absence of appropriate numerical values or biological parameters, criteria should consist of verbal descriptions in sufficient detail as to show clearly the quality of water intended."

On February 27, 1967, the Secretary of the Interior established the first National Technical Advisory Committee on Water Quality Criteria to the Federal Water Pollution Control Administration. The Committee's principal function was to collect in one volume a basic foundation of water quality criteria. A smaller but equally important function was to develop a report on research needs. In its published report the Committee recognized that there is an urgent need for data collection from systematic surveillance of waters and waste sources and for an expanded research effort (Anon., 1968). Systematic surveillance was defined as ". . . traditional sanitary surveys broadened to include aesthetic qualities . . .". The Committee's Report also underscored the relative value assigned to recreational use by the Act with statements that ". . . recreational uses of waters in the United States have historically occupied an inferior position in practice and law relative to other uses," but that today there is a growing realization that recreation is a full partner in water use; one that, with associated services, represents a multimillion dollar industry with substantial prospects for future growth, as well as an important source of psychic and physical relaxation. Water quality research needs including those assigned to fish, other aquatic life, and wildlife have been defined in a 1968 report of the National Technical Advisory Committee.

What, then, is a defined role of the field investigative water pollution biologist? Basically it seems apparent that the role of individuals working in this discipline is to:

1. Determine water quality compliance with established standards, and, determine the effectiveness of established standards to meet the needs of an enhanced water quality.
2. Identify, define, and interpret the effects on aquatic organisms of water quality changes that result from pollution.
3. Project these effects on man and man's use of the water.
4. Predict environmental conditions that might prevail, and beneficial water uses that would result, when pollution that can now be controlled is abated or alleviated, wholly or in some degree.
5. Determine impact of water quality on those important biotic community segments that are either harvestable directly by man or are essential to support more advanced levels of life within the aquatic environment.
6. Contribute to existing knowledge of the cause and control of pest and other nuisance aquatic organism populations.

2

AQUATIC ENVIRONMENTS

Features

AQUATIC environments are as numerous as the very waters themselves. Rising in snowcapped mountains small streams collect the snow melt and transport it to the plains. As these streams meander through the countryside they take from the lands that which is released to them. Small streams soon form larger ones that eventually join to form the great rivers and these in turn terminate in coastal estuaries. Each change in size and shape forms a habitat that becomes unique and supports an assemblage of organisms that is adapted to life in that particular environment. Reservoirs, built by man on rivers, in turn form a particular habitat that is influenced greatly by the reservoir's morphometric features. The reservoir in turn may influence the downstream environement because of the depth of the penstock that releases water of lower temperature, or of less dissolved oxygen, or of higher mineral quality, than the waters that receive it. The landscape is dotted with ponds and with many larger lakes of varying sizes and shapes. Each, as Professor Forbes pointed out many years ago, is a microcosm that supports its own organism community. The Great Lakes are at the pinnacle of lake environments within the United States, and because of their vast size, depths, and currents they offer many environments within their confines.

Organisms that may be found in great numbers in the stream environments are often not adapted to life within the lake or reservoir environments and vice versa. There are many features that tend to make a particular aquatic environement suitable or unsuitable, completely or to some degree, to a particular organism or group of closely associated organism.

Common to all aquatic environments would be the changes brought about by differences among the water habitats. For the pond and lake group these may include:

Altitude	Area
Latitude	Mean depth

Maximum depth
Area of different depth zones
Volume of different depth strata
Length of shoreline
Littoral slope
Drainage area
Runoff rate
Average inflow
Average outflow
Detention time
Water level fluctuation

Number of islands
Island areas
Island shoreline length
Penstock depth (reservoirs).

Features that create particular aquatic environments in flowing water may include:

Altitude
Latitude
Relative extent of pools and riffles
Depth at collection site
Width at collection site
Velocity of flow
Drainage area to collection site
Runoff rate
Physical composition of stream bed
Physical nature of surrounding terrain
Area geology.

The estuarine environment is influenced by morphometric features that are common to both the flowing water and static environments. In addition it is influenced by tidal cycles and their fluctuations.

Life in waters is influenced also by water temperatures, dissolved oxygen, pH, color, turbidities, total dissolved solids, total alkalinity, nutrients and mineral composition. Maximum values, and in some cases minimal values also, of these constituents often create an environment that becomes intolerable to particular organisms and will limit their production or interfere subtly with physiological processes that in turn reduce their ability to compete with others within the environment.

Pollutional Effects

Effects of pollution assume many characteristics and an infinitesimal variaton in degree when pollution enters the aquatic environment. The specific environmental and ecological responses to a pollutant will depend largely on the volume and strength of the waste and the volume of water receiving it. As a basic introduction, five types of responses will be described in subsequent paragraphs, and within each of these response types there can be many changes in magnitude and degree.

The classic response that has often been described in the literature is the effects of organic wastes that may be discharged from sewage treatment plants and certain industries. As these wastes enter the water they

create turbidity, decrease light penetration, and may settle to the bottom in substantial quantity to form sludge beds. The wastes are attacked immediately by bacteria and this process of decomposition consumes oxygen from the water and liberates essential nutrients that in turn stimulate the production of some forms of aquatic life.

Pollutional Zones

Upstream from the introduction of organic wastes, classic description details a clean water zone or one that is not affected by pollutants. At the point of waste discharge and for a short distance downstream there is formed a zone of degradation where wastes become mixed with the receiving waters, and where the initial attack is made on the waste by bacteria and other organisms in the process of decomposition.

Following the zone of degradation there is a zone of active decomposition that may extend for miles, or days of stream flow, depending in large measure on the volume of dilution that is afforded the waste by the stream, and the temperature of the water. The biological processes that occur within this zone are similar in many respects to those that occur in a "typical" sewage treatment plant. Within this zone, waste products are decomposed and those products that are not settled as sludge are assimilated by organisms in life processes.

A zone of recovery follows the zone of active decomposition. The recovery zone is essentially a stream reach in which water quality is grad-

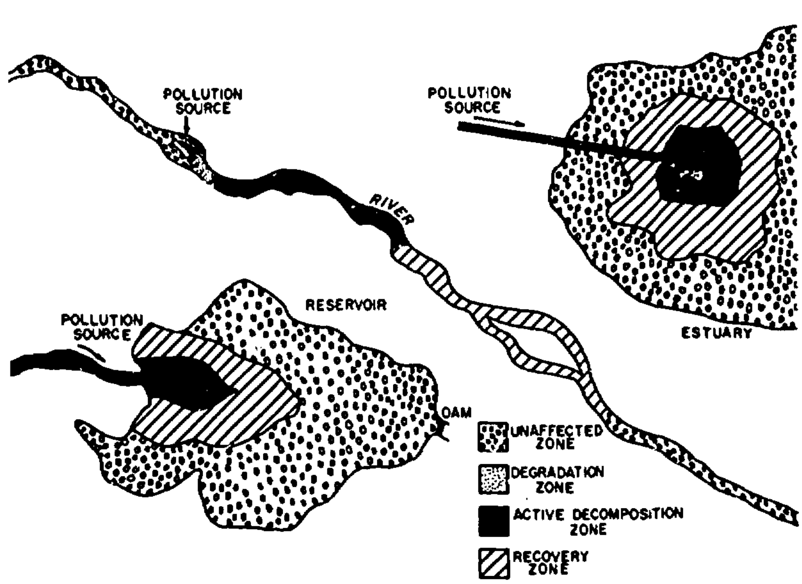

Figure 2. Pollutional Zones

ually returned to that which existed prior to the entrance of pollutants. Water quality recovery is accomplished through physical, chemical, and biological interactions within the aquatic environment. The zone of recovery may extend also for many miles and its extent will depend principally upon morphometric features of the waterway.

Finally the zone of recovery will terminate in another zone of clean water or area unaffected by pollution that is similar in physical, chemical, and biological features to that which existed upstream from the pollution source.

Organic Wastes

The classic description of the effects of organic wastes on the receiving stream often becomes confused in a specific stream investigation, because additional sources of pollution may enter the environment before the receiving water has been able to assimilate the entire effects of an initial source. When this occurs the effects of subsequent introductions become superimposed on those of the initial source and the total effect may confine large reaches of stream to a particular zonal classification.

Effects of organic wastes in the static water environment, as opposed to the flowing water environment, are modified principally by the morphometric features of the receiving water. Zonal changes that have been described for flowing water do exist but may be compressed in great measure either laterally or vertically when the discharge is to a lake or estuary. Such compression may tend to decrease the severity of pollution that is often observed in the flowing water environment and, on the other hand, may increase substantially the development of biotic nuisances such as algae or rooted aquatic plants that may develop from the nutrients released with and decomposed from the introduced organic materials.

Organism communities that may be related to pollution principally are those that are by nature associated with the bed or bottom of the waterway; those that attach themselves to objects such as rocks, aquatic plants, brush or debris submerged within the water; those that are essentially free floating and are transported by currents and wind, such as plankton and other microscopic forms; and those motile free swimming organisms such as fish. Considering each of these common organism groups, a number of observations can be made on their reaction to the introduction of organic wastes to a flowing stream.

Upstream from the waste source such limiting factors as food and intense competition among organisms and among organism groups, predation, and available habitat for a particular species will limit organism populations to those that can be sustained by the particular environment. Most often the limiting factor will be available food. Within this population, however, there will exist a great number of organism species. Thus, the old biological axiom for an environment unaffected by pollution is one

that supports a great number of species with the total population delimited largely by food supply.

Following the introduction of organic wastes, conditions of existence for many organisms become substantially degraded. Increased turbidity in the water will reduce light penetration that in turn will reduce the volume of water capable of supporting photosynthesizing plants. Particulate matter in settling will flocculate small floating animals and plants from the water. As the material settles, sludge beds are formed on the stream bed and many of the areas that formerly could have been inhabited by bottom associated organisms become covered and uninhabitable.

The zone of degradation is a transition area between the clean water unaffected reach and a zone of decomposition of organic wastes. In such, the dissolved oxygen may be diminished but not completely removed. Sludge deposits may be initiated but are not formed in maximum magnitude or extent. Conditions of existence become impaired and typically there is a reduction in both the organism population and the number of species that can tolerate this environment.

Within the zone of active decomposition conditions of existence for aquatic life are at their worst. The breakdown of organic products by bacteria may have consumed available dissolved oxygen. Sludge deposits may have covered the stream bed thus eliminating dwelling areas for the majority of bottom associated organisms that could be found on an unaffected area. Fish spawning areas have been eliminated, but perhaps fish are no longer present because of diminished dissolved oxygen and substantially reduced available food. Here, aquatic plants will not be found in large numbers because they cannot survive on the soft shifting blanket of sludge. Turbidity may be high and floating plants and animals destroyed. Water color may be substantially affected. When organic materials are decomposed a seemingly inexhaustible food supply is liberated for those particular organisms that are adapted to use this food source. Thus, bacterial and certain protozoan populations may increase to extremely high levels. Those bottom associated organisms such as sludgeworms, bloodworms, and other worm-like animals may also increase to tremendous numbers because they are adapted to burrowing within the sludge, deriving their food therefrom, and existing on sources and amounts of oxygen that may be essentially nondetectable by conventional field investigative methods. Within the zone of active decomposition the organism species that can tolerate the environment are reduced to extremely low levels. Under some conditions those bottom associated animals that are visible to the unaided eye may be completely eliminated. Because of the tremendous quantity of food that is available to those organisms that are adapted to use it, the numbers of individuals of the surviving species may, indeed, be great. For example, it may be possible to find 50,000 sludgeworms or more living within each square foot of bottom area with the above-described conditions.

Figure 3. Sludgeworm eggs with embryos.

The zone of recovery is essentially the downstream transition zone between the zone of active decomposition and an environment that is unaffected by pollution. This zone features a gradual cleaning up of the environment, a reduction in those features that form adverse conditions for aquatic life, an increase in organism species, and a gradual decrease in organism population because of decreased food supply and the presence of some of the predators that are less sensitive individually to pollutional affects.

Because of some variation in response among species to conditions of existance within the environment, and because of inherent difficulties in aquatic invertebrate taxonomy, the ecological evaluation of the total organism community is the acceptable approach in water pollution control investigations. At the present time, investigators tend to place organism in broad groups according to the general group response to pollutants in the environment. As we are able to advance our knowledge and determine more specifically the water quality requirements of identifiable species, the

use of specific organism indicators may become more prevalent in biological interpretation. The general group known as "sludge-worms," for example, is found in both the unpolluted, as well as the organically polluted environment. Its value as a group lies in the fact that the numbers of individuals within the group is exceedingly low in unpolluted water, whereas in the organically polluted environment its numbers may be very high. Examples of organisms that may inhabit both the unpolluted and polluted environments are presented in table 1.

The converse of the effects of pollution on organisms is the effects of organisms on pollutants. Organic wastes, especially, supply food which in turn produces an abundance of a few types of organisms greater than that produced in an unpolluted environment. In consuming organic wastes, the organisms stabilize the waste in a given number of feet or miles of horizontal stream in a manner similar to that in a vertical trickling filter that is designed especially for maximum stabilizing efficiency by the organisms.

Purdy (1930) found long ago that sludgeworms eat continuously. Observations during 21 out of 24 hours showed no perceptible decrease in the foraging activity. Evacuation of a string of fecal pellets about 68 inches in length in a 24-hour period was recorded for each worm. An incubation of 24 hours showed an oxygen demand of 2.8 mg./l. by these pellets, whereas the original mud beneath the surface showed a demand of 6.7 mg./l. Purdy's conclusion was that the large surface area of fecal pellets exposed to the flowing water possessed a far greater purification

Table 1. Organism Associations

Clean water association		Polluted water association	
Algae	*Cladophora* (green)	Iron Bacteria	*Sphaerotilus*
	Ulothrix (green)	Fungi	*Leptomitus*
	Navicula (diatom)	Algae	*Chlorella* (green)
Protozoa	*Trachelomonas*		*Chlamydomonas* (green)
Insects	*Plecoptera* (stoneflies in general)		*Oscillatoria* (blue- green)
	Megaloptera (hellgrammites, alderflies, and fishflies in general)		*Phormidium* (bluegreen)
	Trichoptera (caddisflies in general)		*Stigeoclonium* (green)
	Ephemeroptera (mayflies in general)	Protozoa	*Carchesium* (stalked colonial ciliate)
	Elmidae (riffle beetles in general)		*Colpidium* (non-colonial ciliate)
Clams	*Unionidae* (pearl button)	Segmented Worms	*Tubifex* (sludgeworms)
Fish*	*Etheostoma* (darter)		*Limnodrilus* (sludge-worms)
	Notropis (shiner)	Leeches	*Helobdella stagnalis*
	Chrosomus (dace)	Insects	*Culex pipiens* (mosquito)
			Chironomus (*Tendipes*) *plumosus* (bloodworms)
			Tubifera (*Eristalis tenax*) (rat-tailed maggot)
		Snail	*Physa integra*
		Clam	*Sphaerium* (fingernail)
		Fish*	*Cyprinus carpio* (carp)

* Names from: American Fisheries Society Special Publication No. 2, "A List of Common and Scientific Names of Fishes from the United States and Canada" (Second Edition) Ann Arbor, Mich. (1960), 102 pp.

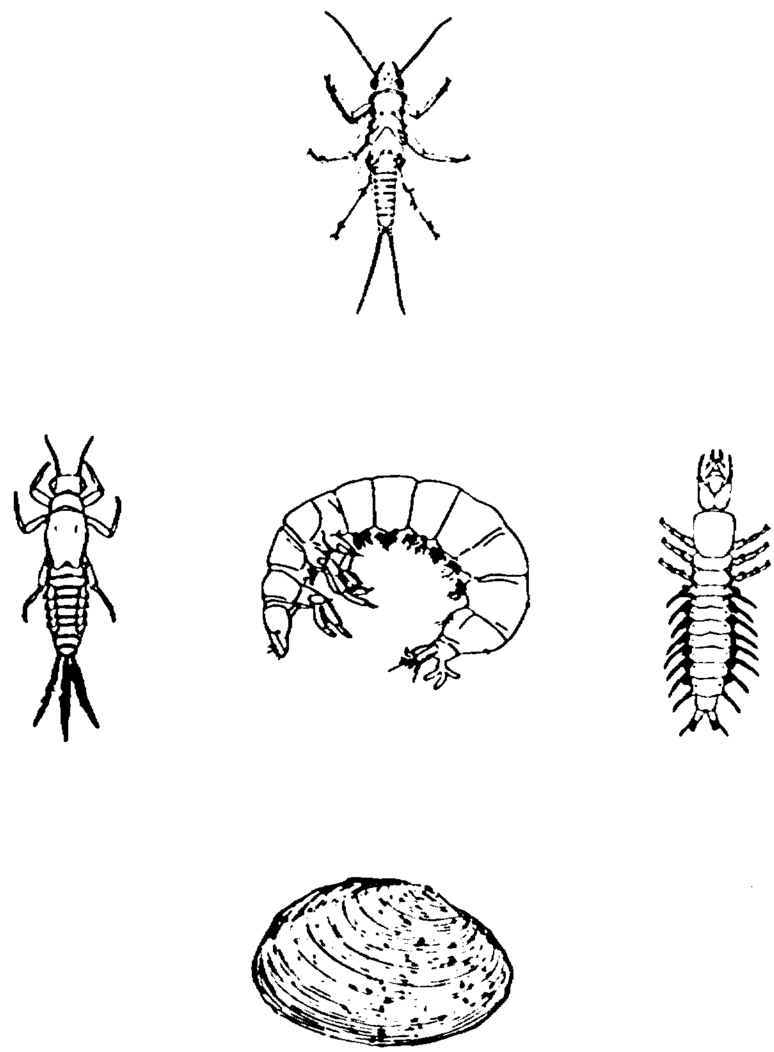

Figure 4. Representatives of stream bed associated animals (The clean water (sensitive) group).

From left:

Stonefly nymph
Mayfly naiad; Caddisfly larvae; Hellgrammite
Unionid Clam

potential than did the same mass of material an inch or more beneath the sludge-water interface.

As organic wastes become more stabilized, other organism types predominate within the aquatic animal community. Midge larvae have been

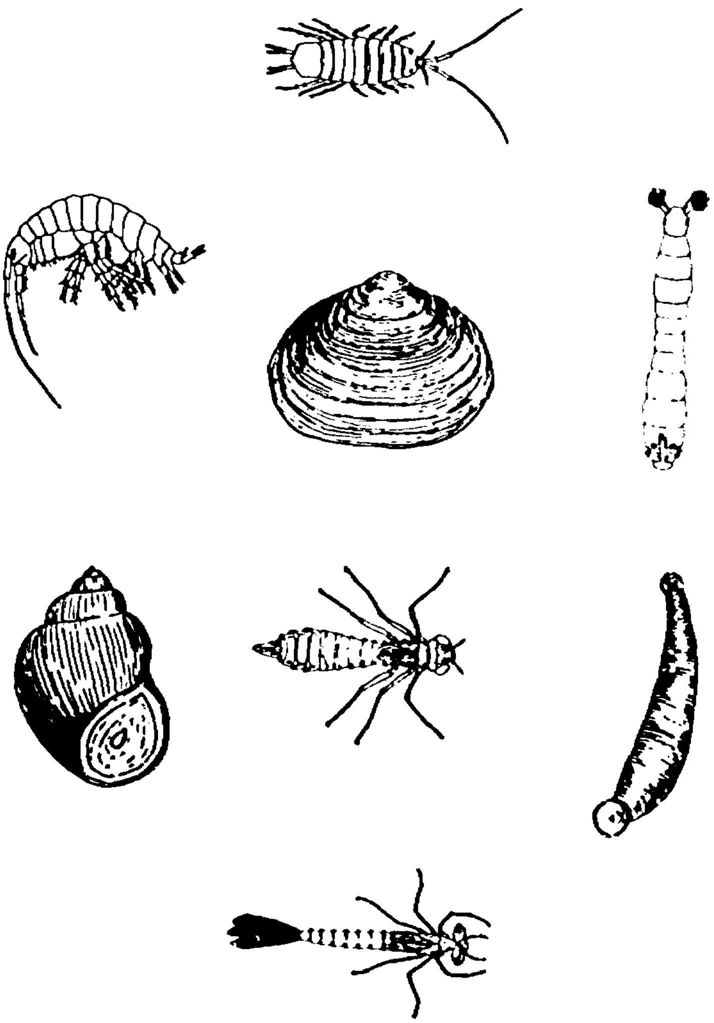

Figure 5. Representatives of stream bed associated animals
(The intermediately tolerant group).

From left:

Scud; Sowbug; Blackfly larvae
Fingernail Clam
Snail; Dragonfly nymph; Leech
Damselfly nymph

found to "paint" the stream bed a brilliant red with their undulating bodies. Caddisfly larval populations greater than 1,000 per square foot of stream bed or mayfly nymphs numbering more than 300 per square foot have been found on several occasions.

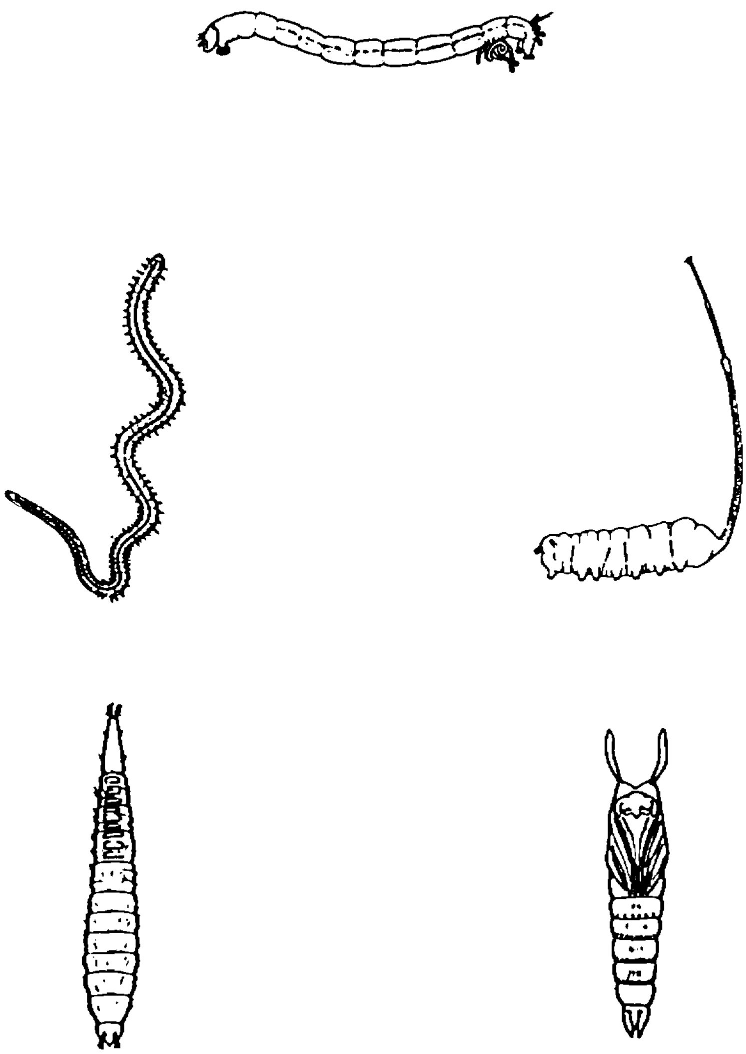

Figure 6. Representatives of stream bed associated animals
(The very tolerant group).

From left:

Bloodworm or midge larvae
Sludgeworm; Rat-tailed maggot
Sewage fly larvae; Sewage fly pupae

The estuarine and marine environments have not been studied as extensively as the fresh-water habitats. Reish (1960) cited Wilhelm (1916) to the effect that the polychaete *Capitella capitata* (Fabricius) plays a role in marine waters similar to that of the oligochaete, *Tubifex*, in fresh water.

Filice (1954) and Reish (1960) found three benthic zones surrounding a major pollutional discharge: one essentially lacking in animals, an intermediate zone having a diminished fauna, and an outer zone unaffected by the discharge. Filice (1959) found the crab *Rhithropanopeus harrisii* (Gould) present more abundantly than expected near industrial outfalls: this crab and *Capitella capitata* (Fabricius) were present in large numbers near domestic outfalls. Hedgpeth (1957) reviewed the biological aspects of the estuarine and marine environments.

Inorganic Silts

The general effect on the aquatic environment of inorganic silts is to reduce severely both the kinds of organisms present and their populations. As particulate matter settles to the bottom it can blanket the substrate and form undesirable physical environments for organisms that would normally occupy such a habitat. Erosion silts alter aquatic environments chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom and destroying living spaces, and by retaining organic materials and other substances that can create unfavorable conditions. Developing eggs of fish and other organisms may be smothered by deposits of silt; fish feeding may be hampered. Direct injury to fully developed fish, however, by nontoxic suspended matter occurs only when concentrations are higher than those commonly found in natural water or associated with pollution.

Toxic Metals

Wastes containing concentrations of heavy metals, either individually or in combination, may be toxic to aquatic organisms and, thus, have a severe impact on the water community. A severely toxic substance will eliminate aquatic biota until dilution, dissipation, or volatilization reduces the concentration below the toxic threshold. Less generally toxic materials will reduce the aquatic biota, except those species that are able to tolerate the observed concentration of the toxicant. Because toxic materials offer no increased food supply, such as has been discussed for organic wastes, there is no sharp increase in the population of those organisms that may tolerate a specific concentration. The bioassay is an important tool in the investigation of these wastes, because the results from such a study indicate the degree of hazard to aquatic life of particular discharges; interpretations and recommendations can be made from these studies concerning the level of discharge that can be tolerated by the receiving aquatic community.

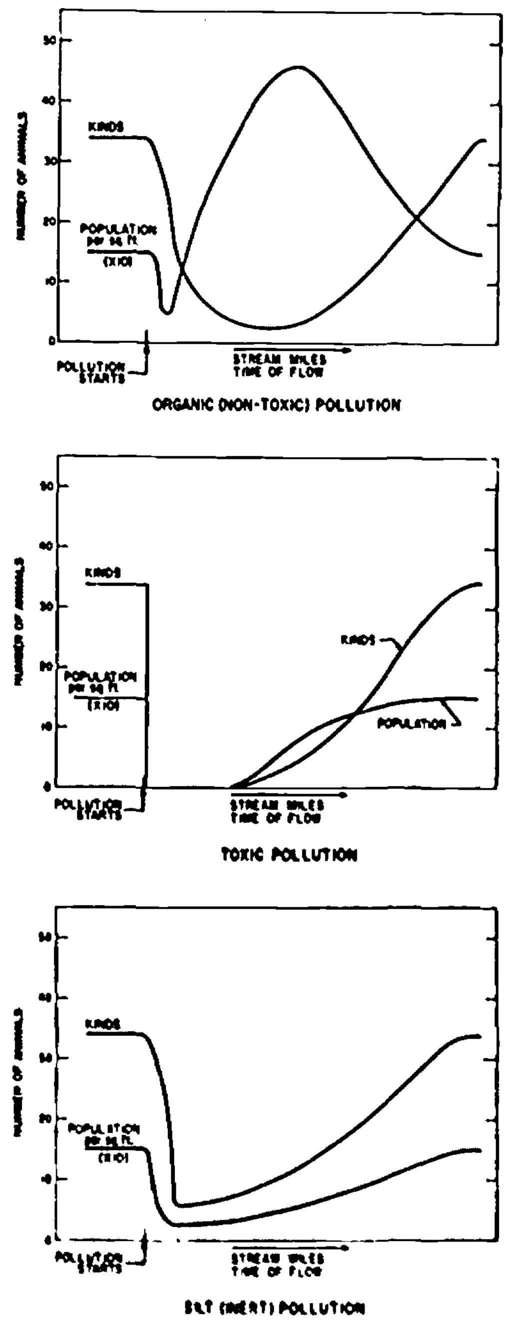

Figure 7. Pollutional Effects on Animals

3

WATER QUALITY CONSTITUENTS

*Temperature**

TEMPERATURE is a prime regulator of natural processes within the water environment. It governs physiological functions in organisms and, acting directly or indirectly in combination with other water quality constituents, it affects aquatic life with each change. These effects include chemical reaction rates, enzymatic functions, molecular movements, molecular exchanges between membranes, etc., within and between the physiological systems and organs of an animal. Because of the complex interactions involved, and often because of the lack of specific knowledge or facts, temperature effects as they pertain to an animal or plant are most efficiently assessed on the basis of net influence on the organism. Depending on the extent of environmental temperature change, organisms can be activated, depressed, restricted, or killed.

Temperature determines those aquatic species that may be present; it controls spawning and the hatching of young, regulates their activity and stimulates or suppresses their growth and development; it can attract and kill when the water becomes heated or chilled too suddenly. Colder water generally suppresses development; warmer water generally accelerates activity.

Temperature regulates molecular movement and thus largely determines the rate of metabolism and activity of all organisms, both those with a relatively constant body temperature and those whose body temperature is identical to, or follows closely, the environmental temperature. Because of its capacity to determine metabolic rate, temperature may be the most important single environmental entity to life and life processes.

Variations in temperature of streams, lakes, estuaries, and oceans are normal results of climatic and geologic phenomena. Waters that support

* Taken from comments presented by Mackenthun, K. M. and L. E. Keup before the 1969 meeting of the American Power Conference sponsored by the Illinois Institute of Technology, Chicago, Ill.

some form of aquatic life other than bacteria or viruses range in temperature from 26.6° F. in polar sea waters to 185° F. in thermal springs. Most aquatic organisms tolerate only those temperature changes that occur within a narrow range to which they are adapted, whether it be high, intermediate, or low on this temperature scale.

Within the same species, the effects of a given temperature may differ in separate populations, in various life cycle stages, or between the sexes, and such effects may depend on the temperature history of the individual tested, as well as on present or past effects of other environmental factors.

Freshwater has the greatest density at 38° F.; higher and lower temperatures result in waters with lower density. Seasonally induced temperature changes are greatest in the midlatitudes.

In lakes, insolation warms the surface waters in spring, reducing their densities compared to the deeper waters until eventually the density differences are sufficient to prevent the wind from mixing the body of water; thermal stratification then occurs. The warm upper layer (epilimnion) is well mixed to a depth determined by wave and other wind induced currents. The cool bottom waters (hypolimnion) become stagnant except for minor currents confined to this strata. A strata of sudden temperature changes (thermocline) separates these regions. In autumn, the lake radiates heat, surface temperatures decrease, surface water density increases, and water viscosity increases. Soon the wind, aided by reduced density differences between water layers, mixes the surface with the bottom waters resulting in a homogenous water mass. Depending on altitude and local climatic conditions, the lake continues to mix until the following spring in latitudes of less than about 40°. In latitudes north of about 40°, winter surface water temperatures are less than 38° F. and these are superimposed over the water mass until they are cooled to freezing. An ice cover eliminates wind induced mixing and stagnation occurs.

Thermal stratification in reservoirs may assume many patterns depending on geographical location, climatological conditions, depth, surface area, and type of dam structure, penstock locations, and hydropower use. In general, large, deep impoundments will cool downstream waters in the summer and warm them in winter when withdrawal ports are deep; shallow, unstratified impoundments with large surface areas will warm downstream waters in the summer; water drawn from the surface of a reservoir will warm downstream waters; a reduction in normal flow downstream from an impoundment will cause marked warming in summer; and "run-of-river" impoundments, where the surface area has not been increased markedly over the normal river area, will produce only small changes in downstream water temperatures.

In the deep, stagnant, summer bottom waters, as well as in ice covered waters, atmospheric reaeration is absent and oxygen from photosynthesis by plants is limited. Decomposing organisms (especially those settling to the bottom waters in summer) remove oxygen from the water and the

gaseous byproducts of decomposition are trapped. Undesirable soluble phosphorus, carbon dioxide, iron, and manganese concentrations increase in these stagnant waters. Designed thermal discharges can reduce some of these problems. Ice cover can be limited, thus allowing wind and thermally induced currents to reduce winter stagnation. A deepwater summer discharge could warm hypolimnetic waters to decrease density and permit total water mass mixing where a cold water fishery would not be damaged by such action.

Stratification may occur in streams receiving heated effluents. There are three recognized forms of stream stratification: overflow, interflow, and underflow; the forms are determined by the relationship between the density of the influent and the density of the stream water.

Surface freshwaters in the United States vary from 32° to over 100° F. according to the latitude, altitude, season, time of day, duration of flow, depth, and many other variables. Agents affecting natural water temperature are so numerous that no two water bodies, even in the same latitude, are likely to have the same thermal characteristics. Fish and other aquatic life occurring naturally in each body of water are those that have become adapted to the temperature conditions existing there. The interrelationships of species, length of daylight and water temperature are so intimate that even a small change in temperature may have far-reaching effects. An insect nymph in an artifically warmed stream, for example, might emerge for its mating flight too early in the spring and be immobilized by the cold air temperature, or a fish might hatch too early in the spring to find its natural food organisms because the food chain depends ultimately on plants, and these in turn, upon length of daylight, as well as temperature. The inhabitants of a water body that seldom becomes warmer than 70° F. are placed under stress, if not killed outright, by 90° F. water. Even at 75° to 80° F., they may be unable to compete successfully with organisms for which 75° to 80° F. is favorable. Similarly, the inhabitants of warmer waters are at a competitive disadvantage in cool water.

An animal's occurrence in a given habitat does not mean that it can tolerate the seasonal temperature extremes of that habitat at one time. The habitat must be cooled gradually in the fall if the animal is to become acclimatized to the cold water of winter, and warmed gradually in the spring if it is to withstand summer heat.

Some organisms might endure a temperature of 92° to 95° F. for a few hours, but not for days. Gradual change of water temperature with the season is important for other reasons: an increasing or decreasing temperature often "triggers" spawning, metamorphosis, and migration. The eggs of some freshwater organisms must be chilled before they will hatch properly.

The temperature range tolerated by many species is narrow during very early development; it increases somewhat during maturity, and decreases

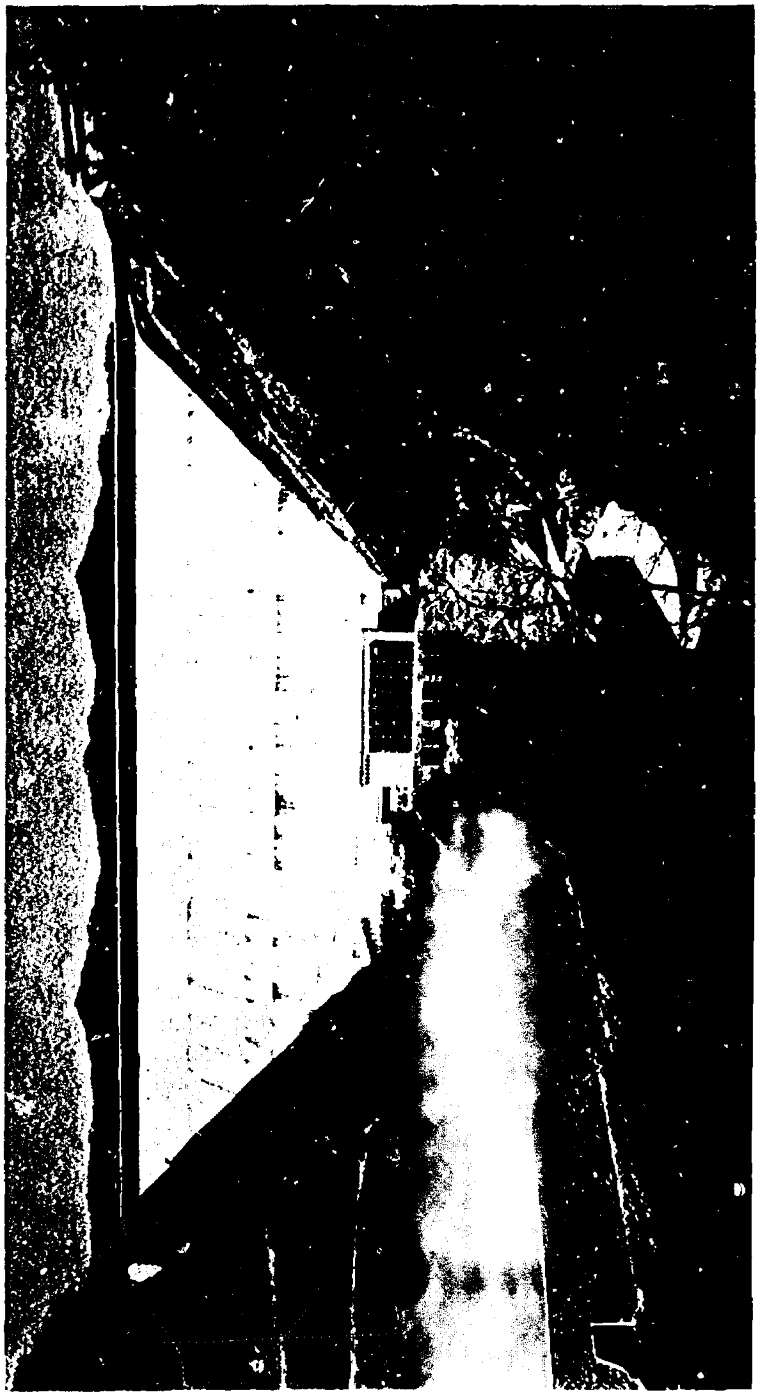

Figure 8. Fontana Project, Tennessee Valley Authority

again in the old adult. Similarly, the tolerable temperature range is often more restrictive during the reproductive period that at other times during maturity. Upper lethal temperatures may be lower for animals from cold water than for closely related species from warm water. Many motile organisms such as fish, some zooplankton, certain algae, and some associated animals can avoid critical temperatures by vertical and horizontal migration into more suitable areas. However, some organisms may be attracted to areas with critical temperatures, and, upon arrival, succumb.

Changes in fish populations can result from many types of artificial cooling and heating of natural waters. These changes result from the discharge of condenser cooling water from thermal electric generating plants, industrial waste cooling waters, and other heated effluents, and irrigation waters. Streams are warmed also by the sun when the shade from stream bank trees and other vegetation is eliminated. The discharge of cold water from stratified impoundments may provide an ideal habitat for trout and other cold water fish, when sufficient dissolved oxygen is present, but not for the warm water fish that inhabited the stream before impoundment.

For every 18° F. increase in temperature, the chemical reaction rate is approximately doubled in an organism or in an environment. Life processes in the water are accelerated with temperature increases and slowed as the water cools.

The solubility of gases, including oxygen, in water varies inversely with temperature. In fresh water, the solubility of atmospheric oxygen is decreased by about 55 percent as the temperature rises from 32° to 104° F. under 1 atmosphere of pressure (760 mm. Hg.). Because all desirable living things are dependent on oxygen in one form or another to maintain the life processes that produce energy for growth and reproduction, dissolved oxygen is of imposing significance in the aquatic environment.

When organism metabolism increases because of higher temperatures, organism development is speeded, and more dissolved oxygen is required to maintain existence. But, bacterial action in the natural purification process to break down organic materials is also accelerated with increased temperatures, thus reducing the oxygen that could be available in the warmer water. When organisms use larger amounts of oxygen, and when oxygen has been reduced by temperature action and interaction, organisms may perish. Life stages that are especially vulnerable are the eggs and larvae. At higher temperatures, phytoplankton have been found to need greater amounts of certain growth factors such as vitamin B_{12}. Between 96.8° and 98.2° F., for example, the vitamin requirement has been found to increase over 300 times for some species.

Fish and other motile organisms seek a preferred temperature at which they can best survive, which is several degrees below a temperature that is lethal. Larger individuals tend to move out of areas that are too hot, but larvae and juveniles cannot often move fast enough to avoid a sudden temperature increase. Large fish and fish in schools avoid heated areas in

summer but may be attracted to such areas in winter. This phenomenon may result in good fishing during the cooler months, but an absence of this sport at other times.

Reproduction cycles may be changed significantly by increased temperature because this function takes place under restricted temperature ranges. Spawning may not occur at all because temperatures are too high. Thus, a fish population may exist in a heated area only by continued immigration. Disregarding the decreased reproductive potential, water temperatures need not reach lethal levels to wipe out a species. Temperatures that favor competitors, predators, parasites, and disease can destroy a species at levels far below those that are lethal.

Fish food organisms are altered severely when temperatures approach or exceed 90° F. Predominant algal species change, primary production is decreased, and bottom associated organisms may be depleted or altered drastically in numbers and distribution. Increased water temperatures may cause aquatic plant nuisances when other environmental factors are favorable.

Synergistic actions of pollutants are more severe at higher water temperatures. Given amounts of domestic sewage, refinery wastes, oils, tars, insecticides, detergents, and fertilizers more rapidly deplete oxygen in water at higher temperatures, and the respective toxicities are likewise increased.

The National Technical Advisory Committee on Water Quality Criteria (Anon., 1968), composed in part of the nation's leading fishery experts, recommended that to maintain a well-rounded population of warm water fishes, heat added to a freshwater stream not exceed that which would raise the water temperature more then 5° F. at the expected minimum daily flow for the month involved. In lakes, the temperature of the upper waters should not be raised more than 3° F. above that which existed before heat was added. The increase should be based on the monthly average of the maximum daily temperatures. Temperature should be measured in those areas where important organisms are most likely to be affected adversely.

The Committee recommended provisional maximum temperatures as compatible with the well-being of various fish species and their associated biota as follows:

93° F.: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.

90° F.: Growth of largemouth bass, drum, bluegill, and crappie.

84° F.: Growth of pike, perch, walleye, smallmouth bass, and sauger.

80° F.: Spawning and egg development of catfish, buffalo, threadfin shad, and gizzard shad.

75° F.: Spawning and egg development of largemouth bass, white and yellow bass and spotted bass.

68° F.: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.

55° F.: Spawning and egg development of salmon and trout (other than lake trout).

48° F.: Spawning and egg development of lake trout, walleye, northern pike, and sauger.

Because of the large number of trout and salmon waters that have been destroyed, made marginal or nonproductive, remaining trout and salmon waters must be protected if these resources are to be preserved. The Committee further recommended that inland trout streams, headwaters of salmon streams, trout and salmon lakes and the deeper waters of lakes that contain salmonids not be warmed. No heated effluents should be discharged in the vicinity of spawning areas.

Little work has been done regarding thermal addition effects in subtropical estuarine ecosystems. In the subtropical environment, optimum temperatures for many forms are only a few degrees lower than maximum lethal temperatures. Organisms may be existing under stress with naturally occurring summer temperatures. Great care should be exercised to prevent harmful temperature increases.

In general, marine water temperatures do not change as rapidly or range as widely as those of freshwaters. Marine and estuarine fishes, therefore, are less tolerant of temperature variation. Although this limited tolerance is greater in the estuarine than in the open water marine species, temperature changes are more important to those fishes in estuaries and bays than to those in open marine areas.

Marine surf-zone discharge from large-scale coastal power plants may be expected to significantly alter the shore environment for species of invertebrates and fish that are commonly found there.

Some investigators have become alarmed over the loss in organisms contained in the water pumped across condensers and through a generating plant. These are subject to thermal shock, physical damage, and perhaps commercial additives. These organisms include phytoplankton, crustaceans, zooplankton, and shellfish larvae, such as clams and oysters that have stages of drift in the water column for a few weeks before they settle to the bottom. Studies have shown a 95 percent mortality of these organisms when they are subjected to the rise in temperature in crossing the condenser.

Available data indicate that commercial and key food-chain estuarine animals cannot tolerate temperatures greater than approximately 90° F. regardless of the temperature to which they have been acclimated. Thus, natural peak summer water temperatures in a subtropical or tropical estuary may be near the tolerance threshold for a number of desirable marine organisms.

In subtropical waters, organisms that find the environment undesirable

are not replaced by organisms of greater temperature tolerance, as so often happens in northern latitudes.

The National Technical Advisory Committee on Water Quality Criteria, in reporting to the Secretary of the Interior, recommended that the discharge of any heated materials into coastal waters be closely managed. This Committee stipulated that any rise owing to such discharges should be restricted to 1.5° F. during the critical summer months, outside of established mixing zones. To make water quality standards more meaningful, mixing zones must have definition. The National Technical Advisory Committee suggested only that adequate passageways be provided at all times for the movement or drift of organisms, and that mixing areas must not be used for, or considered as, a substitute for waste treatment, or as an extension of, or substitute for, a waste treatment facility.

Dissolved Oxygen

Dissolved oxygen (D.O.) is a water quality constituent that, in appropriate concentrations, is essential not only to keep organisms living but also to sustain species reproduction, vigor, and the development of populations. Organisms undergo stress at reduced D.O. concentrations that make them less competitive to sustain their species within the aquatic environment. For example, D.O. concentrations around 3 milligrams per liter (mg/l) or less have been shown to interfere with fish populations through delayed hatching of eggs (Silver et al., 1963), reduced size and vigor of embryos (Silver et al., 1963; Van Horn and Balch, 1957), production of monstrosities in young (Alderdice et al., 1958), interference with food digestion and acceleration of blood clotting (Bouck & Ball, 1965), decreased tolerance to certain toxicants (Cairns and Scheier, 1957), reduced food efficiency and growth rate (Chiba, 1966; Herrman et al., 1962), and reduced maximum sustained swimming speed (Davis et al., 1963).

Oxygen enters the water by absorption directly from the atmosphere or by plant photosynthesis, and is removed by respiration of organisms and by decomposition. That derived from the atmosphere may be by direct diffusion or by surface water agitation by wind and waves, which may also release dissolved oxygen under conditions of supersaturation.

In photosynthesis, aquatic plants utilize carbon dioxide and liberate dissolved and free-gaseous oxygen at times of supersaturation. Since energy is required in the form of light, photosynthesis is limited to the photic zone were light is sufficient to facilitate this process. According to Dice (1952), ". . . the ultimate limit of productivity of a given ecosystem is governed by the total effective solar energy falling annually on the area, by the efficiency with which the plants in the ecosystem are able to transform this energy into organic compounds, and by those physical factors of the environment which affect the rate of photosynthesis." Verduin (1956) summarized the literature on primary production in lakes; based on com-

putations of photosynthetic oxygen production, he found that the yields of several lakes were mostly between 42 and 57 pounds of dissolved oxygen per acre per day. A year-round study under completely natural conditions in western Lake Erie showed winter yields of about 11 pounds of dissolved oxygen production per acre per day, and summer maxima of about 85 pounds per acre per day. The annual oxygen production curve closely followed the solar radiation curve. The net oxygen production rate for East Okoboji Lake in Iowa, a producer of large plankton populations, was 79 pounds per acre per day, with production largely confined to the first 2 meters (Weber, 1958). Whipple et al. (1948) noted that supersaturation in the upper waters is not cumulative to a great extent because circulation is maintained by wind action and convection currents both of which promote contact of the water and the air with a consequent loss of oxygen. Higher saturation is frequently found in the upper region of the thermocline in infertile oligotrophic lakes. Wind action seldom disturbs the waters of this zone, convection currents are absent, and diffusion is a slow process. Plants find an abundant supply of carbon dioxide and sufficient light in this area to stimulate photosynthesis, resulting in supersaturation values that may exceed 300 percent.

During respiration and decomposition, animals and plants consume dissolved oxygen and liberate carbon dioxide at all depths where they occur. Because excreted and secreted products and dead animals and plants sink, most of the decomposition takes place in the hypolimnion; thus, during lake stratification there is a gradual decrease of dissolved oxygen in this zone. After the dissolved oxygen is depleted, anaerobic decomposition continues with evolution of methane and hydrogen sulfide.

In the epilimnion, during thermal stratification, dissolved oxygen is usually abundant and is supplied by atmospheric aeration and photosynthesis. Phytoplankton are plentiful in fertile lakes and are responsible for most of the photosynthetic oxygen. The thermocline is a transition zone from the standpoint of dissolved oxygen, as well as temperature. The water rapidly cools in this region, incident light is much reduced, and photosynthesis is usually decreased; if sufficient dissolved oxygen is present, some cold water fish abound. As dead organisms that sink into the hypolimnion decompose, oxygen is utilized; consequently, the hypolimnion in fertile lakes may become devoid of dissolved oxygen following a spring overturn, and this zone may be unavailable to fish and most benthic invertebrates at this time. During the two brief periods in spring and fall when lake water circulates, temperature and dissolved oxygen are the same from top to bottom and fish can use the entire water depth.

The National Technical Advisory Committee (Anon., 1968) recommended that D.O. concentrations be above 5 mg/l assuming normal seasonal and daily variations for a diversified warm water biota. The Committee stated that under extreme conditions concentrations may range between 5 and 4 mg/l for short periods during any 24-hour period, pro-

viding that the water quality is favorable in all other respects. For cold water biota, it is desirable that D.O. concentrations be at or near saturation especially in spawning areas. D.O. levels in the hypolimnion of lakes should not be lowered below 6 mg/l at any time because of the addition of oxygen demanding wastes. The Committee further specified that D.O. concentrations in surface coastal waters should be greater than 5.0 mg/l, except when upwellings and other phenomena may cause this value to be depressed. D.O. concentrations in estuaries and tidal tributaries should not be less than 4.0 mg/l at any time or place, except in naturally dystrophic waters or where natural conditions cause D.O. to be depressed.

pH

The world's literature on pH published prior to about 1950 has been critically evaluated by Doudoroff and Katz (1950). They concluded that ". . . under otherwise favorable conditions, pH values above 5.0 and ranging upward to pH 9.0, at least, are not lethal for most fully developed freshwater fishes. Much more extreme pH values, perhaps below 4.0 and well above 10.0, also can be tolerated indefinitely by resistant species. However, regardless of the nature of acid or alkaline wastes responsible, such extreme conditions, associated with industrial pollution, are evidently undesirable and hazardous for fish life in waters which are not naturally so acid or alkaline."

Lloyd (1968) summarized the conclusions of the European Inland Fisheries Advisory Commission, Food and Agricultural Organization of the United Nations, with the statement:

> "There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather there is a gradual deterioration as the pH values are further removed from the normal range. The pH range which is not directly lethal to fish is 5–9; however, the toxicity of several common pollutants is markedly affected by pH changes within this range; and increasing acidity or alkalinity may make these poisons more toxic. Also, an acid discharge may liberate sufficient carbon dioxide from bicarbonate in the water either to be directly toxic, or to cause the pH range 5–6 to become lethal.
>
> "Below a pH value of 5.0 fish mortalities may be expected, although some species may become acclimated to values as low as 3.7. However, the productivity of the aquatic ecosystem is considerably reduced below a pH value of 5.0, so that the yield from a fishery would also become less. Some acid waters may contain precipitated ferric hydroxide which may also act as a lethal factor."

The National Technical Advisory Committee (Anon., 1968) recommended for fish and other aquatic life that:

(1) No highly dissociated materials should be added in quantities sufficient to lower the pH below 6.0 or to raise the pH above 9.0.

(2) To protect the carbonate system and thus the productivity of the water, acid should not be added in sufficient quantity to lower the total alkalinity to less than 20 mg/l.
(3) The addition of weakly dissociated acids and alkalies should be regulated in terms of their own toxicities as established by bioassay procedures.

Neel et al. (1961), in studying raw-sewage stabilization ponds, found that pH values above 8.0 are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition; pH levels below 8.0 indicate failure of photosynthesis to utilize completely the amounts of carbon dioxide so produced. "In general practice, pH values above 8.0 are assumed to denote the presence of carbonate; a level of 8.0 indicates bicarbonate alone; and values below 8.0 show the occurrence of free carbon dioxide. Carbon dioxide, usually produced by decomposition and respiration, will react with any carbonate present to form bicarbonate and water. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free CO_2 exists. Carbonates of calcium and magnesium are but weakly soluble and quantities of them leave solution. Decomposition and/or respiration thus tends to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonate" (Neel et al., 1963).

Light

Rooted, suspended, and floating aquatic plants require light for photosynthesis. Light penetration into waters is exceedingly variable in different lakes. Clarke (1939) pointed out that the diminution of the intensity of light in its passage through water follows a definite mathematical formula. The relationship between the depth of water and the amount of light penetrating to that depth can be plotted as a straight line on semilogarithmic paper. Even the clearest waters impede the passage of light to some extent; light passed through 100 meters of distilled water is reduced to 1 or 2 percent of its incident value.

The principal factors affecting the depth of light penetration in natural waters include suspended microscopic plants and animals, suspended mineral particles such as mineral silt, stains that impart a color, detergent foams, dense mats of floating and suspended debris or a combination of these. The region in which light intensity is adequate for photosynthesis is often referred to as the trophogenic zone, the layer that encompasses 99 percent of the incident light. The depth of the trophogenic zone may vary from less than 5 to greater than 90 feet.

The length of daylight in water varies inversely with the depth of the water. The seasonal variation in the intensity of solar radiation influences the potential rate of photosynthesis. In winter the presence of ice with an

over layer of snow further limits the amount of relatively poor incident light energy that reaches the water. The work of Birge, reported by Neess and Bunge (1957), indicates that the absorptive quality of clear ice is very similar to that of water, although the addition of air bubbles or particulate matter reduces the transmission of light. Snow further reduces light penetration through ice. Greenbank (1945) found 84 percent light transmission through 7½ inches of very clear ice, and 22 percent through 7½ inches of very cloudy ice. A 1-inch snow cover permitted only 7 percent light transmission through the ice and snow; 2 inches of snow permitted only 1 percent light transmission. Bartsch and Allum (1957), studying sewage stabilization ponds, found that in the absence of snow 20 to 55 percent of the incident light passed through 10 to 12 inches of ice, whereas, with a 1- to 3- inch snow cover 93 to 99 percent of the incident light was absorbed by ice and snow, when the ice was 1 to 2 feet thick. Mackenthun and McNabb (1961) found less than 1 percent of light passing through 16 inches of ice covered by 2 inches of snow.

Beeton (1958) made 57 paired photometer and Secchi disc measurements at 18 stations in Saginaw Bay in Lake Huron. He found that the average percentage transmission of surface light intensity, at the Secchi disc depth, was 14.7 percent. Verduin (1956) made simultaneous determinations with the Secchi disc and submarine photometer during August, 1955, on Lake Erie. The Secchi disc readings in meters were plotted against the depth associated with 1 percent of the surface light. A line drawn by inspection through the scatter diagram, suggests that an approximate estimation of the depth of the euphotic zone can be obtained by multiplying the Secchi disc readings by 5. Riley (1941) used a factor of 3. Verduin (1956) computed a factor of 2.5 using the data of Bursche (1955). Rawson (1950) listed a factor of 4.3 for a Secchi disc reading of about 1 meter.

Tyler (1968), after extensive experimentation, concluded that Secchi disc readings could be used to plot the depth of the euphotic zone for a particular body of water provided that calibrations had been made against a photometer for that particular water. Tyler further concluded that if modern instruments were available for measuring precise light penetration, that it would probably be better not to undertake such a calibration.

The maximum Secchi disc reading reported for Lake Tahoe, California-Nevada, was 136 feet at one station on April 4, 1962 (McGauhey et al., 1963). A minimum Secchi disc reading of 49 feet was recorded in Emerald Bay of Lake Tahoe on May 21, 1962. In contrast, the Secchi disc disappeared in 3 feet in Lake Sebasticook, Maine, during a July, 1965, study. In areas with less dense algal growths, the readings were increased to 8 feet. Beeton (1965) records the average Secchi disc depth for Lake Superior as 32.5 feet; Lake Michigan, 19.6 feet; and Lake Erie, 14.6 feet.

Flow

The velocity of water movement is extremely important to aquatic organisms in a number of ways including the transport of nutrients and organic food past those organisms attached to stationary surfaces; the transport of plankton and benthos as drift, which in turn serve as food for higher organisms; and the addition of oxygen to the water through surface aeration. Silts are moved downstream and sediments may be transported as bed load. These in turn are often associated with major nutrients, such as nitrogen and phosphorus, which may be released at some point downstream from their introduction.

The determination of flow is necessary to compute pounds of materials passing a given point. Computations are often made on pounds of nitrogen, phosphorus, or other elements of concern, on amounts of plankton and benthos as drift, on amounts of pollutants, such as wool, fibers, or other microscopical identifiable materials that may be associated with a point source.

Flow determines those species of stream bed organisms that may be present in a particular stream reach. Some of these, such as the black fly larva, require fast water. Others, such as the immature forms of caddisflies and mayflies, will develop to large populations in more sluggish water. Among many invertebrate genera there are those particular species that are adapted for life not only under the two extremes of flow but also under its many variations.

Silt

The deposition of sediments in streams can and often does destroy insect and mussel populations. Ellis (1931), in studying the Mississippi, Tennessee, and Ohio Rivers, reported that erosion silts had destroyed a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud was formed, and by smothering young mussels even where the adults could maintain themselves. Ziebell (1957) reported a marked reduction in organisms 100 yards downstream from the discharge of a gravel washing operation entering the South Fork Chehalis River in Washington. Ziebell and Knox (1957) investigated the effects of yet another gravel washing operation on the Wynooche River in Washington. The results of bottom samples collected downstream from the operation revealed reductions of 75 to 85 percent at distances exceeding 1 mile. Silt from a gravel washing plant located on Cold Creek and the Truckee River, Calif. reduced bottom organisms over 75 percent for a distance of more than 10 miles downstream (Cordone and Pennoyer, 1960). Reports published by the Oregon State Game Commission summarized the results of extensive collections of bottom organisms upstream and downstream from gold dredge operations on the Powder River (Anon., 1955). During siltation, production of

fish food organisms decreased to nearly zero in the zone of heaviest pollution and the effect of siltation extended for a distance of 20 miles. In about 1 year after the dredge closed operations, the silt was flushed from the pools and riffles by freshets and bottom organisms increased 8 to 10 fold in weight per unit of bottom area.

Few data are available regarding the direct harm of sediments to fish. In most cases indirect damage to the fish population through destruction of the food supply, eggs, or changes in the habitat probably occur long before adult fish are harmed directly. Ellis (1944) stated that particulate matter of a hardness greater than one, if held in suspension by current action or otherwise, will injure the gills and other delicate exposed structures of fishes, mollusks, and insects when the particles are large enough. Kemp (1949) stated that mud or silt in suspension will clog or cut the gills of many fish and mollusks, and he considered 3,000 p.p.m. dangerous when maintained for a period of 10 days. Wallen (1951) conducted controlled aquarium investigations on the direct effects of turbidity on warm water fishes; he found that observable behavioral reactions that appeared as a turbidity effect did not develop until concentrations of turbidity neared 20,000 p.p.m. and in one species reactions did not appear until turbidities reached 100,000 parts per million (p.p.m.).

The effects of silt upon fish eggs and the developing fry has received greater attention. Stuart (1953) concluded that silt is not very dangerous in the normal streams if excess occurs only at intervals; however, the character of such normal streams can be drastically altered by allowing the washings of quarries, gravel pits, and mines to flow into the streams untreated. In many cases the quantities allowed to enter the stream may be small and the materials in suspension may in itself be of a nontoxic character, but continous application of small quantities over the reeds may by much more detrimental to the welfare of very young fish than sudden flushes of large quantities. Others who have noted the detrimental effects of silt upon the eggs and developing fry of fish include Campbell (1954), Snyder (1959), and Shapovalov and Berrian (1940). Shapovalov and Taft (1954) in discussing mining silt concluded that from a practical standpoint the damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to carry the sediment in suspension.

Turbidity reduces the enjoyment of fishing and may limit fishing success. This effect has been determined in expressable data for Fork Lake in Illinois where it was found that the fish caught per man-hour decreased from 6.53 to 2.04 when the transparency in feet as measured by the Secchi disc was likewise reduced from an average of 4.0 to 1.3 (Bennett, Thompson, and Parr, 1940).

Buck (1956) in a study of 39 farm ponds, rotenoned and then stocked with largemouth bass and bluegill or largemouth bass and redear sunfish were classified into clear ponds-turbidities less than 25 p.p.m., intermedi-

ate ponds-turbidities from 25 to 100 p.p.m., and muddy ponds-turbidities in excess of 100 p.p.m. At the end of two seasons, the average total weight of all fish in clear ponds was about 1.7 times greater than in intermediate ponds and 5.5 times greater than in muddy ponds. Largemouth bass were harmed the most by turbidity in both growth and reproduction. Average volume of net plankton in surface waters of clear ponds was 8 times greater than in intermediate ponds and 12.8 times greater than in muddy ponds.

Sediment is believed to destroy algae by molar action, by simply covering the bottom of the stream with a blanket of silt, or by shutting off the light needed for photosynthesis. Tarzwell and Gaufin (1953) found that turbid waters may transport the byproducts of bacterial action on organic wastes and the effluent of sewage treatment plants considerable distances before they are utilized. When water clears as a result of impoundment so that phytoplankton can grow, fertilizing materials are utilized and may produce troublesome blooms far from the source of pollution. Corfitzen (1939) found that the greatest loss in light intensity was due to light absorption by silt with some additional loss by reflection and refraction.

Attached algae and vegetation are affected by silt principally by: (1) Covering bottom materials with a layer of sediment, (2) reducing light transparency and preventing light penetration, and (3) grinding algae by action of abrasive particles. A reduction of plant food is accompanied by a reduction in the poundage of plant feeding animals that can be supported, and this in turn limits the production of carnivorous animals including fish.

The European Inland Fisheries Advisory Commission, Food and Agricultural Organization of the United Nations, prepared water quality criteria on finely divided solids (Anon., 1965). With respect to chemically inert solids and to waters that are otherwise satisfactory for the maintenance of freshwater fishes they made the following conclusions:

> "(a) There is no evidence that concentrations of suspended solids less than 25 p.p.m. have any harmful effects on fisheries.
>
> (b) It should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 p.p.m. suspended solids. Other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in category (a).
>
> (c) Waters normally containing from 80 to 400 p.p.m. suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range.
>
> (d) At the best, only poor fisheries are likely to be found in waters which normally contain more than 400 p.p.m. suspended solids."

"In addition although several thousand p.p.m. solids may not kill fish during several hours or days exposure, such temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. The spawning grounds of salmon and trout require special consideration and should be kept as free as possible from finely divided solids."

Oil

McKee (1956) in summarizing the effects of oil substances on aquatic life in freshwater, stated that:

"(1) free oil and emulsions may coat and destroy algae and other plankton;
(2) heavy coatings of free oil on the surface may interfere with the natural processes of reaeration and photosynthesis, while light coatings would be less detrimental because wave action and other turbulence would maintain adequate reaeration; and
(3) water soluble principles may exert a direct toxic action."

The deleterious effect of crude oil and lubricating oils on fish is due to a film formed over the gill filaments of fish, which prevents the exchange of gasses and results in suffocation (Klinke, 1962).

The effects of oils on marine animals may include the tainting of fish and shellfish flesh, poisoning by ingestion of oil or soluble fractions, such as phenol, ammonia, and sulfides, disturbances of marine food chains, physical fouling of animals with heavy coats of oil, and repellent effects (Hawkes, 1961).

Many thousands of waterfowl have been destroyed by the effects of oil pollution. This wasteful loss has deprived nature lovers, waterfowl hunters, and bird watchers of immeasurable enjoyment. The destruction of many duck species, such as the canvasback, redhead, and scaups, comes at a critical period for these species that are fighting for survival against the forces of nature. In future years additional waterfowl will be destroyed if oil dumping is continued, especially in late winter. In this modern age of technical development, the discharge of oil into a river system indicates man's lack of responsibility for the preservation of our natural resources.

Erickson (1965) pointed out that the effects of oil on birds depend upon a variety of factors including the type of oil, extent of contamination of plumage, temperature of the air and water, and the quantity of oil ingested. He found that migratory birds are affected indirectly by deposits of oil on the bottom, in shallow water, or along the shore that reduces the available food supply of both plants and animals. Elements within the food chain are eliminated by chemical or physical properties of the oils and food for waterfowl may become unavailable by being overlayed or embedded in the oily materials. Accumulation of petroleum sludge may also prevent germination and growth of plants and the production of invertebrates important as food, either by smothering or by toxic effects.

Oil causes matting of the duck feathers so that ducks become waterlogged, lose their ability to fly and drown if they cannot get out of the water soon enough. It breaks down the insulating power of the feathers; body heat and stored reserves of energy are rapidly lost. Diving ducks may starve, and, following the preening of oil from contaminated feathers, bleeding ulcers may be produced in the digestive tract causing mortality.

Major Nutrients

Eutrophication is a term meaning enrichment of waters by nutrients through either man-created or natural means. Present knowledge indicates that the fertilizing elements most responsible for lake eutrophication are phosphorus and nitrogen. Iron and certain "trace" elements are also important. Sewage and sewage effluents contain a generous amount of those nutrients necessary for algal development.

Lake eutrophication results in an increase in algal and weed nuisances and an increase in midge larvae, whose adult stage has plagued man in Clear Lake, Calif., Lake Winnebago, Wis., and several lakes in Florida. Dense algal growths form surface water scums and algal-littered beaches. Water may become foul-smelling. Filter-clogging problems at municipal water installations can result from abundant suspended algae. When algal cells die, oxygen is used in decomposition, and fish kills have resulted. Rapid decomposition of dense algal scums, with associated organisms and debris, gives rise to odors and hydrogen sulfide gas that creates strong citizen disapproval; the gas often stains the white lead paint on residences adjacent to the shore.

Nitrogen and phosphorus are necessary components of an environment in which excessive aquatic growths arise. Algal growth is influenced by many varied factors: vitamins, trace metals, hormones, auxins, extracellular metabolites, autointoxicants, viruses and predation and grazing by aquatic animals. Several vitamins in small quantities are requisite to growth in certain species of algae. In a freshwater environment, algal requirements are met by vitamins supplied in soil runoff, lake and stream bed sediments, solutes in the water, and metabolites produced by actinomycetes, fungi, bacteria, and several algae.

Evidence indicates that: (1) High phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary, and they produce such growths in one geographical area, but not in another. Potential contributions of phosphorus to the aquatic environment have been indicated in the literature (table 2).

Keup (1968) in flowing water studies found that phosphorus is tempo-

rarily stored in bottom sediments or transported as a portion of the stream's bed-load after its removal from the flowing water. Long-term storage is affected when the phosphorus is pooled in deltas or deposited on flood plains. Keup reviewed the literature on phosphorus discharges by specific streams (table 3).

Once nutrients are combined within the ecosystem of the receiving waters, their removal is tedious and expensive; removal must be compared to inflowing quantities to evaluate accomplishment. In a lake, reservoir, or pond, phosphorus is removed naturally only by outflow, by insects that hatch and fly out of the drainage basin, by harvesting a crop, such as fish, and by combination with consolidated bottom sediments. Even should adequate harvesting methods be available, the expected standing crop of algae per acre exceeds 2 tons and contains only about 1.5 lbs of phosphorus. Similarly, submerged aquatic plants could approach at least 7 tons/acre (wet weight) and contain 3.2 lbs/acre of phosphorus. Probably only half of the standing crop of submerged aquatic plants can be considered harvestable. The harvestable fish population (500 lbs.) from 3 acres of water would contain only 1 lb. of phosphorus.

Dredging has often been suggested as a means of removing the storehouse of nutrients contained within the lake bed sediments. These sediments are usually rich in nitrogen and phosphorus, for they represent the accumulation of years of settled organic materials. Some of these nutrients are recirculated within the water mass and furnish food for a new crop of organic growth.

Hasler (1957) found that, in an undisturbed mud-water system, the percentage of nutrients, as well as the amount of phosphorus that is released to the superimposed water, is very small. In laboratory experiments, when P^{32} is placed at various depths in the mud, the diffusion into the overlying noncirculating water is negligible, if the phosphorus is

Table 2. Pounds of Phosphorus Contributed to Aquatic Ecosystems

Major Contributors:

Sewage and Sewage Effluents: 3 lbs. per capita per year.*
Some industries, e.g., potato processing: 1.7 lb. per ton processed.
Phosphate rock from 23 States (Mackenthun and Ingram, 1967).
Cultivated agricultural drainage: 0.35 0.39 lb. per acre drained per year (Engelbrecht and Morgan, 1961) (Sawyer ,1947) (Weibel, 1965).
Surface irrigation returns, Yakima River Basin: 0.9 3.9 lbs. per acre per year (Sylvester, 1961).
Benthic Sediment Releases.

Minor Contributors:

Domestic duck: 0.9 lb. per year (Sanderson, 1953).
Sawdust: 0.9 lb. per ton (Donahue, 1961).
Rainwater.**
Groundwater, Wis.: 1 lb. per 9 million gals. (Juday and Birge, 1931).
Wild duck: 0.45 lb. per year (Paloumpis and Starrett, 1960).
Tree leaves: 1.8 3.3 lb. per acre of trees per yeer (Chandler, 1943).
Dead Organisms; animal excretions.

*Various researchers have recorded the annual per capita contribution of phosphorus in pounds from domestic sewage as 2 to 4 (Bush & Mulford, 1954), 2, 3 (Mentzler et al., 1958), 1.9 (Owen, 1953), and 3.5 (Sawyer, 1965).

**Influenced by pollution present in atmosphere "washed out" by rainfall.

Table 3. Phosphorus Discharged by Selected North American Streams (from Keup, 1968)

Principal land use	River	Number of analyses	Season of sampling	Drainage area (mile²)	P—P (lb/annum/ mile²)	Population density mile²	Reference*
Forested	West Branch Sturgeon R, Mich	27+	July	14	37	Sparse	A.
	Pigeon, Minn	4	Aug. and Sept	600	28	Sparse	B, C, D.
	Poplar, Minn	4	Aug. and Sept	114	21	Sparse	B, C, D.
	Baptism, Minn	4	Aug. and Sept	140	42	Sparse	B, C, D.
	St. Louis, Minn	4	Aug. and Sept	3430	58	Sparse	B, C, D.
	Bois Brule, Wis	4	Aug. and Sept	113	97	Sparse	B, C, D.
	Bad, Wis	4	Aug. and Sept	611	78	Sparse	B, C, D.
	Montreal, Wis	4	Aug. and Sept	281	98	Sparse	B, C, D.
	Black, Mich	4	Aug. and Sept	202	65	Sparse	B, C, D.
	Presque Isle, Mich	4	Aug. and Sept	260	39	Sparse	B, C, D.
	Ontonagon, Mich	4	Aug. and Sept	1290	44	Sparce	B, C, D.
	Yakima, Wash	?	Annual	182	473	Sparse	E.
	Tieton, Wash	?	7 months	237	492	Sparse	E.
	Cedar, Wash	?	Annual	125	204	Sparse	E.
	Mulligan, Maine	12	4 seasons	21	4	Sparse	F.
	Stetson, Maine	19	4 seasons	29	20	Sparse	F.
	East Branch Sebasticook, Maine	56	4 seasons	56	128†	> 63‡	F.
	Ellerslie, Prince Edward Island	≈44	April-Dec	10	113	Sparse	G.
	Pigeon, N. C.	18	July	133	97	Light	This article.
	Johnathans, N. C.	5	July	65	201	Light	This article.
	Kankakee, Ind. and Ill	6	June-Sept	5280	139	28	H, I.
	Vermillion, Ill	8	June-Sept	230	179	36	H, I.
	Fox, Ill. and Wis	7	June-Sept	2570	489	145	H, I.
Agricultural	Kaskaskia, Ill	100	April-Dec	5220	225	>174‡	J.
Urban	Streams near Madison, Wis	?	?	?	235-262	?	K.
	Du Page, Ill	5	June-Sept	325	18	380	H, I.
	Des Plaines, Ill. and Wis						
	Above confluence with Chicago River	5	June-Sept	635	570	1270	H, I.
	Total basin (includes Chicago River)	19	June-Sept	2180	4020	2570	H, I.
	Chicago, Ill	16	June-Sept	810	6540	5650	H, I.

*Data given, or computed from data in the refernces. A. Ball and Hooper (1963). B. Putnam and Olson (1959). C. Putnam and Olson (1960). D. Anon. (1964). E. Sylvester (1961). F. Anon. (1966). G. Smith (1959). H. Hurwitz, et al. (1965). I. Anon. (1963). J. Engelbrecht and Morgan (1961). K. Sawyer (1947).

†One seasonal (9 months) industry contributes approximately 75 per cent. ‡Only sewered population known.

placed more than 1 c.m. in the mud. Application of lime to the water or mud reduces the amount of soluble phosphorus released. Acidification of previously alkalized mud will, upon agitation, increase the amount of phosphorus entering solution. In an aquarium experiment, circulation of the water above phosphorus-rich mud, with the aid of air bubbles, increased the phosphorus in solution.

Zicker et al. (1956) found in laboratory experiments that the percentage of phosphorus released to water from radioactive superphosphate fertilizer placed in an undisturbed mud-water system was very small, with virtually no release of phosphorus from fertilizer placed at depths greater than ¼ inch below the mud surface. Radiophosphorus placed ½ inch below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at a 1-inch depth did not diffuse into the water at all.

Dredging deepens an area within a lake and can be beneficial if the increased depth is sufficient to prevent growth of larger nuisance plants. Dredging uncovers yet another soil strata that will contain phosphorus in some quantity, subject to solution in water. The newly dredged area immediately begins to receive organic fallout from waters above, and forms a new interface at which nutrient exchange is substantial. Sediments disturbed during a dredging operation liberate nutrients at a rate more rapid than sediments left undisturbed and all of these factors must be considered when recommending dredging for nutrient removal. Based entirely on nutrient considerations, dredging can be advantageous only when it removes sediments that contain a higher concentration of nutrients than the interface likely to be formed by fallout.

The total supply of an available nutrient depends on the total volume of water, as well as the concentration of the element in the water. Gerloff and Skoog (1957) in laboratory investigations determined that 5 units of nitrogen plus 0.08 unit of phosphorus (a ratio of 60:1) would produce 100 units of algae. The N-P ratio, as it naturally occurs in algae and submerged plants, is more nearly 10:1. Allen (1955) found that to obtain any appreciable increase it was necessary to supplement the sewage with nitrogen as well as carbon.

Sawyer (1947) studied the southeastern Wisconsin lakes and concluded that a 0.30 mg/l concentration of inorganic nitrogen (N) and a 0.01 mg/l concentration of soluble phosphorus (P) at the start of the active growing season could produce nuisance algal blooms. Nitrogen appears to be the more critical factor limiting algal production in natural waters (Gerloff and Skoog, 1957), since phosphorus is stored in plankton as excess and may exceed the actual need.

Sawyer (1954) discussed factors that influence the development of nuisance algal growths in lakes. The surface area is important since the accumulations of algae along the shoreline of a large lake under a given set of wind conditions could easily be much larger than on a small lake,

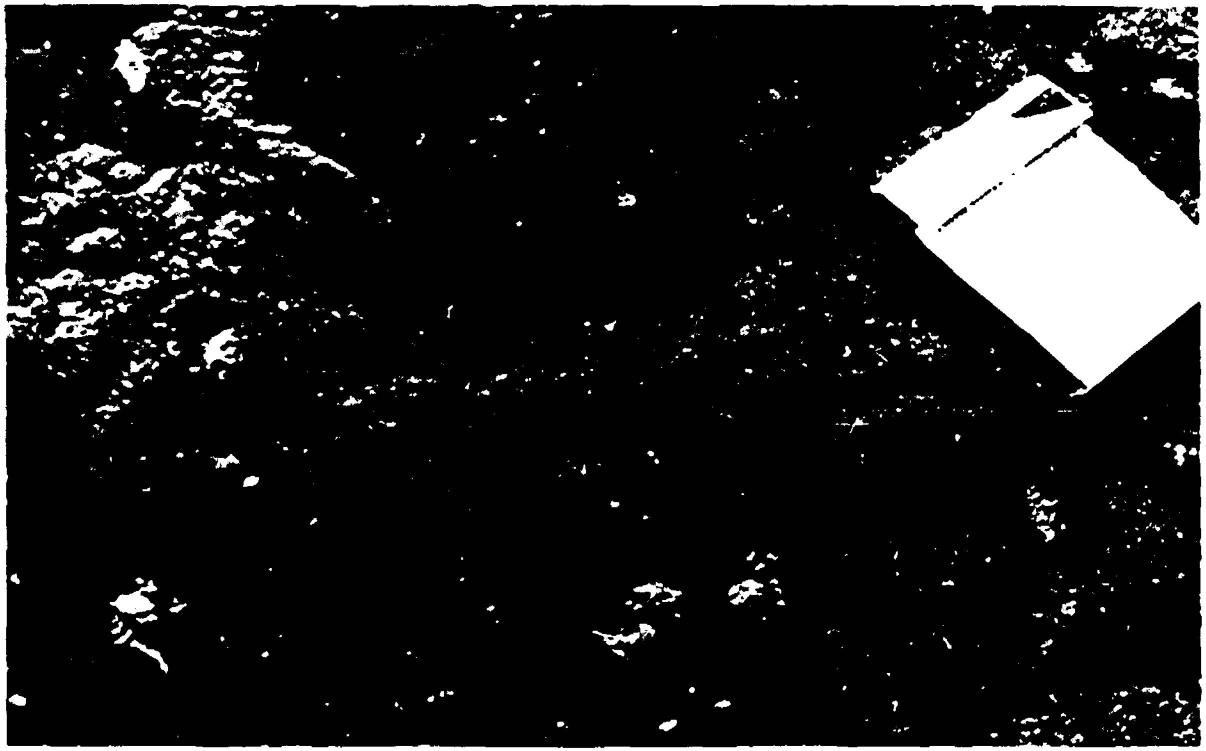

Figure 9. A Blue-green Algal Nuisance

under equal fertilization per acre. The shape of the lake determines to some degree the amount of fertilizing matter the lake can assimilate without algal nuisances since prevailing winds blowing along a long axis will concentrate the algal production from a large water mass into a relatively small area. The most offensive conditions develop during periods of very mild breezes that tend to skim the floating algae and push them toward shore. Shallow lakes, too, respond differently from deep stratified lakes in which the deeper waters are sealed off by a thermocline. In the nonstratified waters all the nutrients dissolved in the water are potentially available to support an algal bloom. In stratified waters, only the nutrients confined to the epilimnion are available except during those brief periods when complete circulation occurs.

Lund (1965) in his thorough literature review stated that "Nitrogen and phosphorus can still be considered as two of the major elements limiting primary production. In some tropical and highly eutrophic temperate lakes, nitrogen may be a more important limiting factor than phosphorus. In many other lakes phosphorus is present in very low concentrations and seems to be the major factor limiting production. Evidence from the addition of fertilizers to fish ponds and from what is known about the eutrophication of lakes by sewage supports the view that phosphorus plays a major role in production."

Chu (1943) found that optimum growth of all organisms studied in cultures can be obtained in nitrate-nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward. The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l; and the upper limit from 8.9 to 17.8 mg/l when nitrate is the cource of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

Experiments by Ketchum (1939) with the diatom *Phaeodactylum*, showed a reduction in rate of cell division when phosphate present in the medium is less than 17 micrograms per liter (μg/l) P. Strickland (1965) stated that the limiting phosphorus concentration in some cultures has been found to be less than 5 μg/l. The problem is complicated because auxiliary compounds may affect the availability of phosphate to a plant cell. Sylvester (1961) found that nuisance algal blooms were observed in Seattle's Green Lake (a very soft-water lake) when nitrate nitrogen (N) levels were generally above 200 μg/l and soluble phosphorus (P) was greater than 10 μg/l.

Müller (1953) concluded that excessive growths of plants and algae in polluted waters can be avoided if the concentration of nitrate nitrogen is kept below about 0.3 mg/l and the concentration of total nitrogen is not allowed to rise much above 0.6 mg/l.

The question is sometimes asked, how much algae can be grown from a given amount of phosphorus? Allen (1955) found that the maximum that could be grown in the laboratory on sewage was 1 to 2 g/l (dry weight) and in the field in sewage oxidation ponds the maximum was 0.5 g/l. Thus, assuming optimum growth conditions and maximum phosphate utilization, the maximum algal crop that could be grown from 1 pound of phosphorus would be 1,000 pounds of wet algae under laboratory conditions or 250 pounds of wet algae under field conditions. Considering a phosphorus (P) content of 0.7 percent, 1 pound of phosphorus could be distributed among 1,450 pounds of algae on a wet weight basis.

A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 μg/l P at any point within the flowing stream, nor should 50 μg/l be exceeded where waters enter a lake, reservoir, or other standing water body. Those waters now containing less phosphorus should not be degraded (Mackenthun, 1968). Adequate phosphorus controls must now be directed toward treatment of nutrient point sources and to wastewater diversion around the lake or dilution within the lake, where feasible.

Micronutrients

It is generally conceded that abundant major nutrients in the form of available nitrogen and phosphorus are an important and a necessary component of an environment in which excessive aquatic growths arise. Algae, however, are influenced by many and varied factors. Vitamins, trace metals, hormones and auxins, extracellular metabolites, autointoxicants, viruses, and predation and grazing by aquatic animals are factors that stimulate or reduce algal growths. Some of these may be of equal importance to the major nutrients in influencing nuisance algal bloom production.

Harder, in 1917, is credited with first connecting growth inhibiting substances with algae. As early as 1931, autoinhibiting substances were recognized (Akehurst, 1931). These papers gave rise to a common belief that a plant can create its self-destruction through the production of growth inhibiting substances that it cannot tolerate but which may, in turn, stimulate other growths. Natural waters contain these active agents that are secreted and excreted by freshwater algae. The toxicity of these agents to other algae and bacteria and to fish varies constantly and is not well understood in the natural aquatic environment. It has been postulated that algae secrete not just one substance but several, some antibiotic, others stimulating. The amount secreted and the net result of the secre-

tions would be determined by the prevelence of one group of substances over the other. Thus, sequences of algal blooms may be expected to occur under conditions of a nutrient supply far in excess of critical values.

In man's quest to reduce major nutrients enriching waters, such as nitrogen and phosphorus, and thereby restore such waters to a greater water use potential without attendant algal pests, other algal population-influencing factors will have a role in the ultimate success of the restoration efforts. This role is presently neither clearly defined nor understood. It does seem clear that the constant progression of the geologic clock cannot be substantially altered. Despite man's most ardent dreams, lakes now fertile and abundantly productive of algae will never again attain their crystal-clear, pristine appearance so well imprinted in the minds of long-time local residents. The old-swimmin-hole lingers on in local folklore. Recently defiled waters can be improved substantially, however, by reducing or removing the varying causes of algal productivity. By placing all known algal population influencing factors in their proper perspective and by intensifying investigative efforts directed towards the interrelationships of factors most likely to effect population controls, knowledge and nuisance reducing efforts will be enhanced. Lakes, reservoirs, ponds, flowing streams, estuaries, and bays will be improved, and the using public will be benefited.

Eyster (1964) divided the elements required by green plants into macronutrients and micronutrients. Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, calcium (except for algae where it is a micronutrient), and sodium. Micronutrients include iron, manganese, copper, zinc, molybdenum, vanadium, boron, chlorine, cobalt, and silicon.

Manganese is one of the key elements in photosynthesis and manganese-deficient cells have a reduced level of photosynthesis and a reduction in chlorophyll. Iron is associated with nitrogen metabolism. Arnon (1958) confirmed that chloride is a coenzyme of photosynthesis specifically concerned with oxygen evolution. Vanadium and zinc appear to be involved in photosynthesis. Calcium and boron are involved in nitrogen fixation. Molybdenum is necessary for nitrate utilization and nitrogen fixation. Cobalt is associated with the nutritional functions of vitamin B_{12}.

Fitzgerald (1964) discussed the sequences of algal blooms that occur under conditions of nutrient supply in sewage stabilization ponds far in excess of those found in natural lakes. He also reviews some of the factors other than nutrition that might influence the algal population. These factors include grazing and the production of inhibiting extracellular products. It is pointed out that there is evidence that an inverse relationship frequently exists between the density of phytoplankton and zooplankton. This might be the result of over-grazing in specific areas and a lack of grazing in adjoining areas or it may be due to an "exclusion" effect on zooplankton produces by extracellular plant metabolites. Gibor (1957)

has shown evidence that algae can at times pass through the zooplankton without being affected by digestive processes.

In situations where the algae are so abundant that their control may be required by chemical means, it appears that animal predation or attacks by micro-organisms are not enough to cause a shift in the dominant species. Once the dominant species is eliminated, however, other species increase in numbers and become dominant. Factors thought to contribute to species dominance include secreted or excreted inhibiting extracellular products (Rice, 1954).

Léfevre (1964) stated that when an algal species develops extensively in standing waters causing waterblooms, it eventually becomes intoxicated by its own accumulated excretion products and dies. When the water is renewed slowly, this phenomenon does not occur because the extracellular products are constantly removed. Also, when one species of algae predominates in standing water, other species appear only sporadically and the number of bacterial species decreases. Léfevre et al. (1952) suggested that this phenomenon is due to antagonistic substances produced by the prodominant species. Léfevre (1964) stated that the production of extracellular active agents Is conditioned by: (1) Nature of strain; (2) composition of culture medium; (3) nature and size of inoculum; (4) temperature; (5) illumination; (6) agitation of medium; (7)duration of culture; and (8) season of the year.

Of 154 algal species, 56 require no vitamins and 98 species require vitamin B_{12}, thiamin and biotin, alone or in various combination (Provasoli, 1961). Those blue-green algae not requiring B_{12} employ it readily as a cobalt source; since cobalt is generally scarse in water, even organisms not requiring B_{12} may compete for it. A great part of the vitamins in freshwaters and in the littoral zone of the sea can be assumed to come from any soil run-off especially during the spring floods. Muds are another source of vitamins. A third source is the vitamins present as solutes in water.

Vitamins are synthesized by several organisms. *Chorella* has been found to produce as much as 6.3 μg B_{12} per 100 g. of dry algae and *Anabaena* as much as 63 to 110 per 100 g. of dry algae (Brown et al., 1955). Burkholder (1959) studied the production of B vitamins by 344 bacteria isolated from waters and muds from Long Island Sound and found that 27 percent of these gave off vitamins B_{12}, 50 percent gave off biotin, 60 percent thiamine, and 11 percent nicotinic acid. Sixty-five percent of the actinomycetes studied were found by Burton and Lockhead (1951) to produce vitamin B_{12}. Robbins et al. (1950) reported that fungi and many bacteria, isolated from the water and mud of a pond in which *Euglena* blooms, produces B_{12}; they demonstrated also that these bacteria, grown with *Euglena* on agar plates of a medium deprived of B_{12}, diffused sufficient vitamin to support growths of *Euglena*. And Robbins and Ka-

vanagh (1942) stated that the ability of a fungus to synthesize vitamins essential for their metabolic processes may be complete, incomplete, or absent.

Toxic Substances

Many pesticides and heavy metals are toxic to aquatic life in low concentrations. Many studies have related these toxicities to specific organisms and to specific dilution waters. The toxicity of a particular substance is dependent to a large extent on other water quality characteristics associated with the toxicant, such as temperature, pH, alkalinity, etc. The National Technical Advisory Committee (Anon., 1968) presented criteria for many of these elements and compounds based upon the present state of the art. In many instances it is necessary to determine through bioassay the toxicity to fish or other aquatic organisms by testing the particular effluent discharged with the particular water quality that receives the discharge.

4

PROBLEM SOLVING

SOLVING a field water quality problem involves the following principal points:

A. Objectives

B. Investigation

1. Study Planning
2. Data Collection
3. Sample and Data Analyses

C. Reporting

1. Data Organization and Display
2. Interpretation
3. Report Writing
   a. Introduction
   b. Summary
   c. Conclusions
   d. Recommendations
   e. Predictions
   f. Area Description
   g. Water Uses
   h. Waste Sources
   i. Effects on Water Quality
   j. Appendix

D. Demonstrations

Objectives

Careful thought should be given to the development of study objectives. These should encompass clear, concise, positive definitions of the investi-

gation's purpose, its scope, and its boundary limitations. Study objectives should be realistically oriented to the numbers, competencies and disciplines of investigative personnel involved, to budgetary limitations for the study, and to the length of time allocated to the study, including final report preparation. Ultimately as the study progresses and it concluded, its success and accomplishments will be judged on the satisfaction, or degree of satisfaction, of the objectives stated at the instigation of the project. Study objectives become extremely important tools to guide and control subsequent investigation, to delineate avenues of approach towards problem solving, and eventually to judge success.

Planning

A field investigation encompasses three equally important areas of activity: study planning, data collection, and sample and data analyses. Study planning involves a myriad of details.

First, maps of the waterway in question must be secured and points of access noted. Tentative sampling stations should be selected from the maps based on points of access, and stream-mile designations developed for major landmarks on the waterway and the tentatively selected sam-

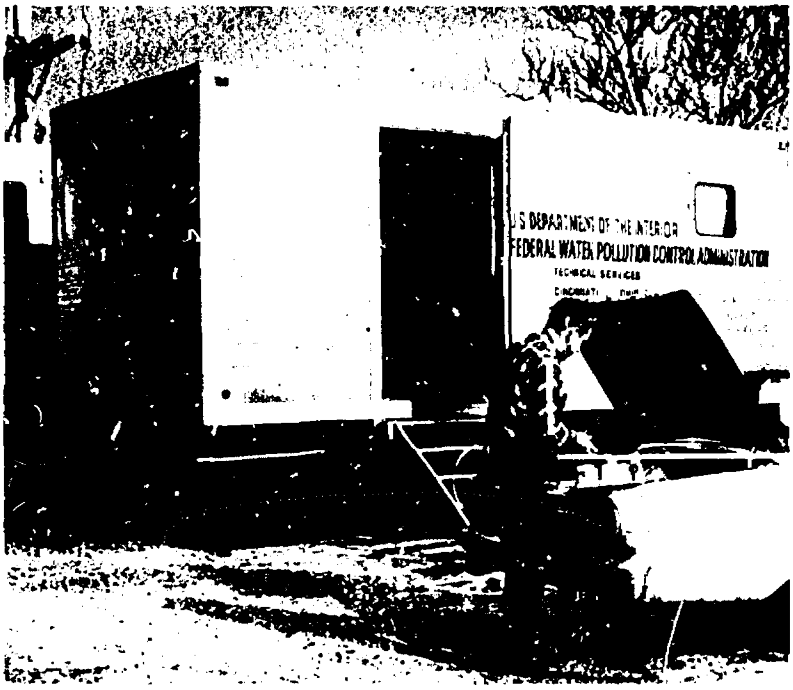

Figure 10. Mobile chemical and microbiological laboratories receiving samples near river bank.

pling stations. Development of stream mileages necessitates that the maps be accurate and of suitable scale.

Following a "desk top" analyses of available background data and other information related to the problem in question, a reconnaissance survey is indicated of the reach of waterway to be studied, as well as principal contributing pollution sources. During the reconnaissance survey a judgment is reached on the potential effects on water quality of individual waste sources, the reach or reaches of waterway that are of potentially greatest concern in the particular investigation, and possible sampling sites and actual points of access. A judgment should be reached on the advantages and disadvantages of sampling the entire waterway by boat as opposed to a cartop or trailered boat that is lowered into the water from several points of access along the waterway. Perhaps answers to the problem can be satisfactorily obtained by sampling the stream while wading and, should this be the case, much time, effort, and expence could be saved in so doing. Observations should be made at various points of access on stream width, depth if ascertainable, nature and type of stream bed, relative flow, as well as any other morphometric features that would seem to contribute towards a better organized sampling procedure when samples are collected. It is extremely important to know where boats and other equipment may be lowered into the waterway and possible difficulties that may be encountered when this is done. It is equally important to ascertain that proportion of the samples that may be collected by wading or by some means other than by boat. Observations should be made that may later relate to the use of such gear as conventional biological sampling dredges, square foot stream samplers, and various types of fish nets or seines. During the reconnaissance survey contacts can be made with local officials or local investigators who may be encouraged to participate in some manner with the investigation. Arrangements should be made with land owners to cross private lands at times when samples are to be collected from the waterway, should this be necessary.

Water samples for chemical analyses should be collected from access points along the waterway during the reconnaissance survey to ascertain the relative magnitude of pollution at various points, and to aid in the judgment of selecting sampling stations. Concurrently the aquatic organisms that can be observed qualitatively on rocks and other submerged objects should be noted and recorded for similar use.

Following the completion of a reconnaissance survey, and subject to modification or change during the course of the field sampling, decisions can be made on the following:

1. Types of samples necessary to point to a solution to the problem (i.e. plankton, periphyton, benthos, vascular plants or fish)
2. Sampling points for each of the selected types of samples

3. Periodicity of sampling and approximate collection time for a specific sample type and
4. Approximate number of samples necessary to complete the study.

A field investigation of a problem that demands the services of a biologist or the collection of biological samples should be investigated also by the chemist, the microbiologist, the sanitary engineer, and perhaps a representative of another pertinent discipline. It goes without saying that particular points in the development of solutions to specific problems are not confined specifically to the biological discipline, but instead must be a consideration of any discipline's representative engaged in the study. Thus, the points that are discussed herein are related specifically to the biologist but can be used with appropriate modifications for associated disciplines. Indeed, biological data will serve to complement chemical, physical, and other data in the process of formulating a solution to a specific problem.

The next aspect of study planning involves, logically, the carrying out of details that are necessary to initiate the process of data collection. Decisions must be made on methods of sample handling, sample preservation, and transportation of samples to a base laboratory. In the conduct of biological investigations these decisions are often not complex. Samples are placed in appropraite sample containers, usually preserved with a solution of formaldehyde and transported to a base laboratory either at the completion of the field study or at intervals by commercial transportation. The number of samples expected to be collected during an investigation will determine the relative number of sample collection containers that must be made ready for the study. Sampling equipment, data cards, notebooks and all of the necessary paraphernalia associated with the collection, retention, and shipment of biological samples must be organized and arrangements made to transport same to the study site either at the study instigation or by commercial means in time to ensure its being on hand when the investigators arrive.

A part of the study planning involves the making of travel arrangements, room accommodations, transportation of samples and equipment both to and from the sampling area, and arragements for such items as outboard motor gasoline, cartons for shipping collected samples, and ice for sample preservative, if this is a necessary consideration.

Adequate survey planning can save so much time and expense during the field study that it is worthwhile to make a list of judgments that are necessary during this planning stage, as well as a list of items that are necessary to ensure a succesful survey. By checking this list one can reduce the possibility of oversight that otherwise would be a cause of frustration at a later time.

In addition, a preliminary survey of pertinent literature is of extreme importance. Data that are already available may serve as guides to addi-

Figure 11. Laboratory analyses being conducted inside mobile laboratory.

tional investigation. A thorough study of the most complete maps of the study area will facilitate both organizational planning and initial field investigation.

Station Selection

Preliminary to the collection of a sample, the investigator must firmly establish the location of sampling stations. Station selection varies with the physical features of the waterway and this discussion will relate to streams, lakes, reservoirs, and estuaries.

Biological sampling stations for the stream environment should be routinely located close to or at those sampling stations selected for chemical

and microbiological analyses to enhance interpretation through the use of interrelated data. Sampling stations should be located upstream and downstream from suspected pollution sources, and from major tributary streams, and at appropriate intervals throughout the stream reach under investigation. The upstream stations should depict conditions unaffected by a pollution source or tributary. The nearest downstream station to the pollution source or tributary should be so located that it leaves no doubt that conditions depicted by the sample can be related to the cause of any environmental change. The minimum number of downstream stations from this point should be located in the most severe area of the zone of active decomposition, downstream in an area depicting less severe conditions within this zone, near the upstream reach of the zone of recovery, near the downstream reach of the recovery zone, and in the downstream reach that first shows no effect from the suspected pollution source. Precise station location will depend on the flow, the strength, volume and type of pollution entering at the source, and the entrance of additional sources of pollution to complicate the stream recovery picture. When water in tributary streams is found to be polluted or to influence water quality in the primary stream, these streams should be similarly investigated.

A stream usually is composed of riffles and pools. These areas will vary in depth, velocity of flow, and types of substrate that form the stream bed. Because the biologist seeks to determine changes that occur in water quality as depicted by aquatic organisms and to relate these changes to particular sources, he must compare observations at a particular station with observations and findings from an upstream station, as well as a station within the stream reach that is unaffected by a suspected source. To accomplish this an effort should be made to collect samples from habitat types that are morphometrically similar. Riffle samples should be compared with riffle samples and pool samples compared with pool samples. Both should be studied where feasible. To determine the extent of each major environmental change produced by pollution, the biological investigator may need to choose a number of stations in addition to those selected for routine chemical or bacteriological sampling.

Plankton samples are collected usually at one point within the study station, most commonly at midstream 1 to 2 feet below the surface. Samples for bottom associated organisms should be collected at a number of points on a transsection line between the stream banks. Optimally, these samples should be collected at a minimum of (5) points across the stream (mid and two quarter points and at near zero water level with banks); more than one sample may, at times, be collected from each point and retained separately. Realistically the objectives of a particular survey and the number of stations at which bottom fauna are collected may dictate the number of samples from a particular station. Attached growths are sampled wherever they occur.

The receiving waters from a lake or reservoir should be studied in the same manner as influent streams. The effluent of a natural lake will usually give a better than average composite of the epilimnionic waters of the lake. The discharge from a reservoir penstock located below the thermocline, however, will not give a representative sample of the productive zone of the reservoir but shows water quality in a portion of the hypolimnion instead. A study would be indicated to show the effect of the low-level discharge on the receiving waters.

Within the lake or reservoir, a number of sampling sites may be chosen depending on the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants often proves useful for future comparisons. Fish sampling

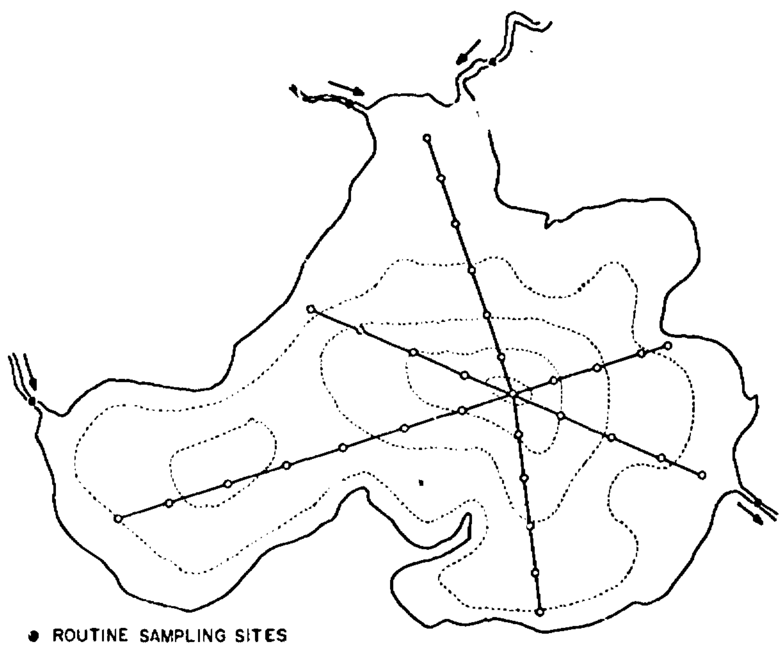

Figure 12. Diagram of a natural lake basin showing suggested sampling sites. Samples taken from points on transaction lines on a periodic or seasonal basis are valuable to determine vertical water characteristics and the benthic standing crop.

also is often more profitable in shallow water areas, although gill nets set in the region of the thermocline and below may sample a fish population not usually observed in shallow water.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed beds and the upper extent of the hypolimnion, concentration zones may be missed entirely or inadequately represented. Maximum benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections from a transection will sample all depth zones, and a sufficient number of samples must be taken to make the data meaningful.

A circular lake basin should be sampled from several transections extending from shore to the deepest point of the basin. A long narrow basin is suitable for regularly spaced parallel transects that cross the basin perpendicular to the shore, beginning near the inlet and ending near the outlet. A large bay should be bisected by a transection originating near shore and extending to the lake proper.

There are definite advantages in sampling the benthic population in winter beneath the ice cover in lakes. Samples can be collected at definite, spaced intervals on a transection, and the exact location of sampling points can be determined. Also, collections are at a time of peak benthic population when emerging insects do not alter the benthic population.

Transactions also aid in sampling the palnkton population. Because of the number of analyses necessary to appraise the plankton population, however, more strategic points are usually sampled, such as water intakes, a site near the dam in the forebay area or discharge, constrictions within the water body, and major bays that may influence the main basin. Because of significant population variation, plankton samples must be taken vertically at periodic depths, and at different times over the 24-hour day.

Reservoirs are usually long and narrow water bodies with the widest portions occuring downstream. They are particularly suitable for the placement of imaginary transection lines that extend perpendicularly from one shore to the opposite shore. Sampling stations can be conveniently located on these transections. In addition water use return waters or areas designated for water use removals should be sampled.

The selection of sampling stations in estuaries combines the aspects of stream sampling with those of the more static lake environment. Water within the estuary is controlled by tides and the force of water discharged by the river and, because of this, particular constituents of water quality

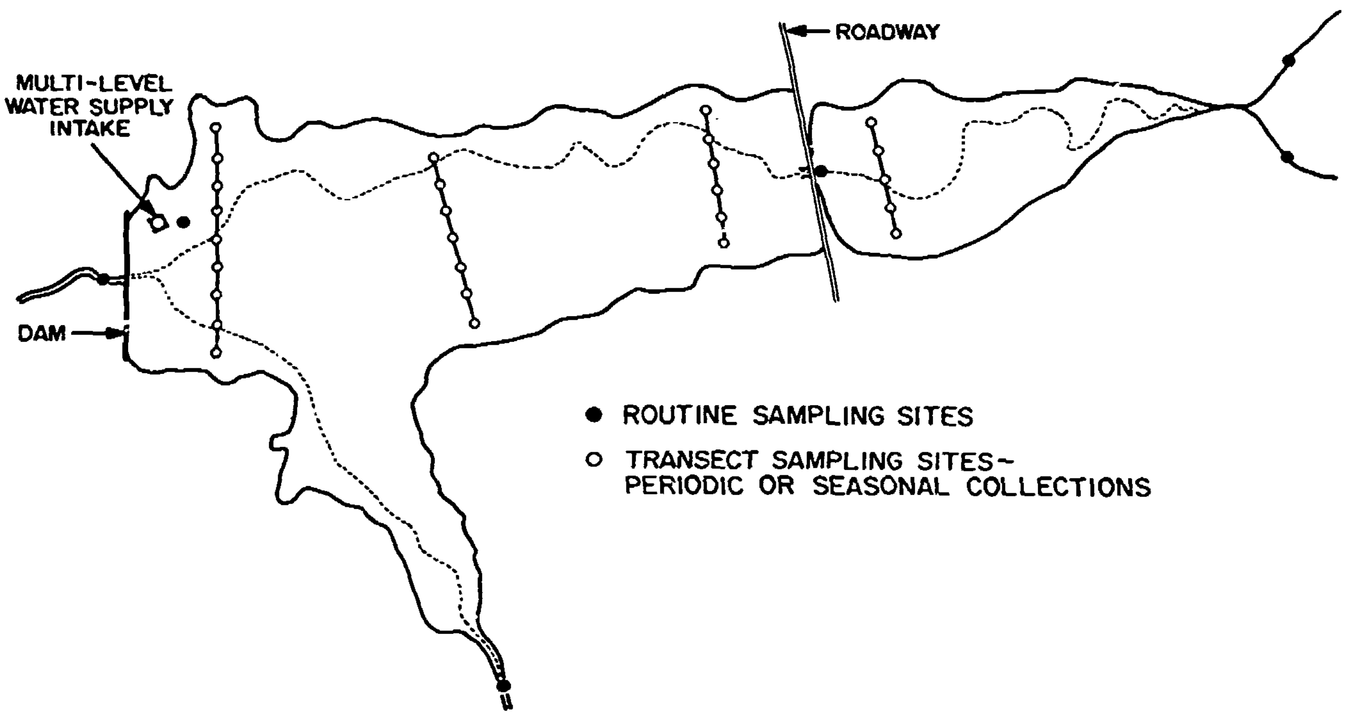

Figure 13. Diagram of a long, narrow reservoir showing suggested sampling stations.

may remain localized in a given area for a considerable period of time before they are dispersed or carried out to sea. Thus, the flow characteristics of the water mass are extremely important in order to define water quality and prognosticate effects of waste discharges on it. The flowing water portion of an estuarine study should be attacked in a manner similar to that described for the stream environment. Sampling stations within the true estuary can be profitably developed along transection lines that either cross the estuary, more or less perpendicularly from one shore to another, or that extend out of the estuary in two or more directions from a suspected point source of pollution. Whenever possible, samples should be collected from areas that represent the estuarine habitat unaffected by pollution, as well as areas that depict environmental changes produced by it.

Sampling Periodicity

Weekly collections, as a minimum, are desirable throughout the season of active biological growth to measure planktonic populations and chemical constituents that may change rapidly. In special studies, samples are often collected daily or even periodically during a 24-hour day to assess these changes. During the non-growing season, monthly samples of these constituents should be adequate except where otherwise indicated by the objecives of the study. A reconnaissance and mapping of the aquatic vegetation should be done during maximum vegetation growth, usually in midsummer.

Insect representatives of the bottom organism community emerge from the water as adults periodically throughout the warm weather period; time of emergence depends on the species involved. Life histories of these organisms tend to overlap so that at no time is there a dearth of these organisms within the bottom associated community. Bottom fauna should be sampled during the annual seasons; the standing crop will be highest, however, during the fall and winter periods when insect emergence is minimal, and one of the sampling dates should reflect this period.

Because of the report deadline or limited personnel available, the theory and practice of station location and sampling periodicity may not be the same. The objectives of a study may be met by investigating only bottom fauna and attached organisms in a stream, and these on only one occasion. Much can be learned from this minimal effort. The investigator should keep in mind that water quality effects from organic wastes will likely be at their worst during the warm weather low-flow period. When streams become covered with ice in northern climes during winter, another period with severe conditions of existence for bottom fauna occurs in late winter. The zone of active decomposition resulting from an organic waste source will be transferred a considerable distance downstream under ice cover.

Little knowledge may be gained from only one series of plankton samples from a stream. Because these organisms are carried by the currents, a given sample is representative of water quality at some point upstream rather than at the place of sampling.

Data and Sample Collection

The collection of data and samples from a particular station involves making a number of scientific observations. Flow measurements on streams, inlets and outlets to standing bodies of water such as lakes and reservoirs, suspected municipal and industrial waste sources, and water use drawoff and return points, which can be correlated with sampling dates, are of utmost importance. Such data permit a calculation of the amounts of particular water quality constituents passing a point at a given time, and estimates can be made from these data on daily, monthly, or annual contributions. Rainfall may be a contributing factor to investigations concerning major aquatic plant nutrients and should be sampled to determine annual contributing amounts of nitrogen and phosphorus. A house-to-house survey of the area draining to a watercourse may be indicated to determine types of waste treatment and to project potential impact of wastes that are discharged to or reach the watercourse. The types and amounts of fertilizers applied to lands within the drainage basin, as well as the period of the year when fertilizers are applied, may be of importance to the study. Groundwater may be a factor and should be sampled from appropriate adjacent wells for those constituents of importance.

On approaching a stream station a number of observations must be made that will later be considered in interpreting the biological findings.

Observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae, and other aquatic plants, as well as red sludgeworm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

Organisms associated with the stream bed are studied most often in the biological evaluation of water quality. These organisms are valuable to relate water quality because they are not equipped to move great distances through their own efforts and, thus, remain at fixed points to indicate water quality. Because the life history of many of these organisms extends through 1 year or longer, their presence or absence is indicative of water quality within the past, as well as the present. Bottom associated organisms are relatively easy to capture with conventional sampling equipment and the amount of time and effort devoted to their capture and interpretation is not as great as that required for other segments of the aquatic community.

The investigator should ask himself three basic questions: Based on a knowledge of preferred organism habitats, what bottom fauna should I

expect to find at this station? Specifically, where would I expect to find these creatures? What is the appropriate gear with which to capture them? A close search of the respective areas should be made noting and collecting qualitatively the various types of organisms. A commercial 30-mesh sieve is a handy exploratory tool.

The qualitative search for benthos should involve the collection of organisms from rocks, plants, submerged twigs or debris, or leaves of overhanging trees that become submerged and waterlogged. It is often convenient to scrape and wash organisms from these materials into a bucket or tub partially filled with water and then to pass this water through the sieve to concentrate and retain the organisms. The collected sample may be preserved for organism sorting and identification later. The investigator should search until he is certain that he has collected the majority of species that can tolerate the particular environment. In some environments it

FIELD COLLECTION CARD

Date __________ Hour ______ Collector __________

Field Designation ____________________

Station Location ____________________

Sample No. ______________ Stream M __________

Weather ____________________

Bottom: _____ Rock: _____ C. Gravel F. _____ d F. _____

% : _____ Sandy Loam: _____ Silt Loam: _____

: _____ C. Clay F. _____ : _____ Organi

Sample Location ______________ Sample Depth ______

River: Width ________ Depth ________ Current ________

: Temp ________ DO ________ pH ________

: Phth Alk ________ Tot Alk ________ Cond ________

Sampler : Ek : Pet : Sq Ft : Qual : :

No. of Samples: : : : : :

Fish: Gear : Shocker : Dip Net : Seine : :

Sample Time : : : : :

Sample Area : : : : :

Remarks:

Figure 14. Field Collection Card for Benthic Samples.

Desired items for a field biological collection card may be arranged on a 5" × 8" unlined card for convenience. Cards can be carried in a field notebook; they may be filed after field and laboratory use. The backside of the card may be ruled to itemize the organisms observed in the laboratory examination of the collected sample.

is possible only to collect qualitative samples because the physical nature of the waterway may be such that quantitative sampling is not feasible.

Qualitative sampling determines the variety of species occupying a reach of a waterway. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but they generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced in the stream because of adverse conditions from 100 to 1 per square foot, whereas sludgeworms may increase from 1 to 14,000 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms.

The basic principal in qualitative sampling is to collect as many different kinds of animals as practical. Obviously, because of the rarity of some forms, the probability of collecting a specimen of every kind is remote and a limit must be imposed on the collector's efforts. Two convenient limiting methods are:

(1) Presetting a time limit on the collector's effort at each sampling point. A minimum of 30 minutes and a maximum of an hour is a convenient range in which to establish this limit.

(2) Sampling in an area until new forms are encountered so infrequently that "the law of diminishing returns" dictates abandoning the sampling point. This method requires professional judgment —but if after 10 minutes only a single species or organism is found, the sampler can move to the next sampling site where he might continue to find new forms after searching more than an hour.

A number of tools readily obtained in any community are valuable in this type of sampling:

a. Pocket-knives are excellent tools to remove animals from crevices in rocks, to peel bark from decaying logs thus exposing animals, and to slip under animals to lift and transfer them to sample containers.
b. Mason jars in ½ to 1 pint sizes serve as the most economical sample containers and provide visibility of the preserved specimens.
c. Common garden rakes are valuable to retrieve rocks, brush, logs and aquatic vegetation for inspection.
d. Fine-meshed dip-nets are good devices for sweeping animals from vegetation or out from under over-hanging rock ledges.
e. Buckets are handy to quickly receive rocks and debris, thus preventing escape of the swift running animals.
f. Sheet polyethyelene, 6 x 6 feet, can be spread on the stream bank and substrate materials placed upon it. As the materials begin to dry the animals will abandon their hiding places and can be seen readily as they migrate across the sheet seeking water.

g. U.S. Standard Series No. 30 soil sieves can be used to scoop up fine sediments and sieve out its inhabitants. The entire qualitative sample can also be screened to standardize the organism sizes taken at various sampling sites.

h. Any other tools, such as forceps, scalpels, shovels, and forks are legitimate devices and can prove their merit in individual situations.

Following these general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) The sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those form. predominant in the area and encountered during the qualitative search.

Bottom samples in lakes usually may be collected with an Ekman dredge, although the physical composition of the bottom determines to a great extent the type of samples that must be used to collect an adequate sample. The Ekman dredge (Ekman, 1911) consists of a square box of sheet brass 6 x 6 inches in cross section.* The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The hinged top of the box may be equipped with a permanent 30-mesh screen to prevent loss of organisms if the samples sinks into mud deeper than its own height. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates. The Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

The Petersen dredge (Petersen, 1911) is a most versatile stream bed sampler to collect bottom life. It is widely used to sample hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron, clam-type dredge, samples an area of 0.6 to 0.8 square foot, and weighs between 35 and 70 pounds depending on the rare use of additional weights that may be bolted to its sides. By means of a rope, the dredge is slowly lowered to the bottom to avoid disturbing and flushing away significant lighter materials. As tension is eased on the rope, the mechanism holding the jaws apart is released. As the rope is again made taut, a sample is secured. The operator controls the dredge by maintaining tension on the rope until the dredge is placed. This is helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and by carefully manipulating the dredge, can secure a better sample than would otherwise be possible. In streams with gravel and rub-

* Ekmans are made also in 9" x 9" and 12" x 12" sizes, but because of size of grabs, these are almost impossible to operate effectively on many occasions. Through long experience the author recommends only the 6" x 6" size.

Figure 15. Biological collecting equipment. From left, Kemmerer sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

ble beds that permit wading, another technique is for the investigator to place the dredge and then stand on the jaws working them into the stream bed with his weight, thus gradually closing them. When the dredge is surfaced, careful and rapid placement and subsequent discharge, endwise, of the dredge into a bucket whose lip is placed at the water's surface prevents loss of material.

The orange-peel dredge, is a multijawed, round dredge with a canvas closure serving as a portion of the sample compartment. It is available in a variety of sizes. Its sampling area is a function of depth of penetration and this area must be calibrated, usually with the volume of sediment contents. It has received wide use in marine waters and in the Great Lakes, where it has advantages over other tools for sampling sandy substrates.

The ponar dredge is receiving increased use in deep lakes. In comparative studies it is more efficient than the Petersen dredge when samples are secured from deep (>100 feet) waters. In appearance it is similar to a Petersen dredge but it has side-plates and a screen on the top of the sample compartment.

The Smith-McIntyre dredge has the heavy steel construction of the Petersen, but its jaws are closed by strong coil springs. Its principal advantage is its stability or operator control in rough waters. Its bulk and heavy weight requires operation from large boats equipped with a powered winch.

Core samplers have been used to sample sediments in depth and collect small areas (2–4 sq. inches) of the mud-water interface. Their efficient use requires dense animal populations. Corer design varies from hand-pushed tubes to explosive driven and automatic surfacing models. The Phleger type is the most widely used corer in water quality studies. It is a gravity corer, relying on its weight (near 100 lbs.) to drive its sample tube into the substrate. The length of core retained will vary with substrate texture; 30 inches is near the maximum length. A core of this length is adequate for most physical, chemical or fossil examination to delineate recent environmental changes.

The Wilding, or stove-pipe, sampler is the only sampler that will quantitatively sample the fauna inhabiting the bottom and/or the vegetation in areas with dense aquatic weed growths. Its operation may be restricted to the vegetation, or mud-water interface sediment may be included.

Drift nets may be suspended in flowing waters to capture invertebrates that have migrated into the water mass from the bottom substrates and are temporarily being transported by currents. Their principal uses have been to study migratory movements and to evaluate sublethal toxicants, especially insecticides, on the fauna. Before toxicants become lethal the animals are weakened and cannot maintain their benthic position and thus are swept away by the currents and carried into the nets.

These nets must be standardized in an individual study. As of now no single style of net has been standardized among investigators. It is recommended that these nets be designed with a 1 x 1 foot upstream opening, with U.S. Standard Series No. 30 netting (or finer, with subsequent screening for uniform organism size), and with a net-bag length of 36 inches.

After suspension in the water, these nets require constant tending. Within a fraction of an hour the nets efficiency is reduced through clogging of the net by drifting animals and detritus that soon results in significant volumes of water and organisms being diverted around the mouth of the net.

Other sampling gear, and their uses, will be described in the 13th Edition of Standard Methods for the Examination of Water and Wastewater.

After the bottom sample is collected by one of the deepwater sampling devices, it is brought to the surface and placed in a large pail or tub. Water for sample dilution is added to the pail, and the sample is mixed into a slurry with the slurry finally being passed through a U.S. Standard No. 30 mesh sieve while the sieve is being rotated in the water. The washing operation is repeated until all fine material has passed through the sieve, and all organisms are retained in the sieve. The organisms and coarser debris are then removed form the sieve and are preserved. It is often easier to sort the organisms from the debris when the organisms are alive. Time schedules and extensive field operations, however, often dictate that sample collection and examination take place at different times during the year. Wide-mouthed, tapered pint freeze jars, obtainable from most grocery stores, have proven to be excellent bottom organism sample containers. When these jars are filled half full with 10-percent formalin before the days activities of sample collection, it is a time-saving process to transfer the concentrated sample from the side of the sieve to the jar of preservative by lightly hitting the sieve against the top of the jar. The investigator is assured always of a minimum of 5-percent formalin in the sample container, a sufficient strength to preserve the collected organisms. After the samples are preserved in the field they are returned to the laboratory where the organisms are separated from the debris, placed in respective groups, identified, and enumerated.

To sample riffle areas in streams, a square-foot bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

In practice, it may be found convenient to remove the larger rocks from inside the sampling frame, placing them in a bucket or tub partially filled with water. Here, the organisms can be washed or scraped from the rocks, and concentrated by a sieve as described earlier, before being combined with those from the Surber sampler in a sample jar with preservative.

Artificial substrates have been successfully employed in studying bottom fauna in flowing streams. One multiple-plate sampler constructed of tempered hardboard (Hester and Dendy, 1962) has been especially suitable for studying stream inhabitants in those streams that do not possess a natural substrate suitable for the attachment of benthic forms. A sampler constructed of eight 3-inch squares, separated by seven 1-inch squares, and held in place by a bolt or threaded rod exposes slightly more than 1 square foot of surface to which organisms can attach.

Artificial substrates are placed in the water for 3- to 6-weeks and then carefully removed to prevent losing the organisms that have made them a temporary home. As nearly as possible the substrates should be placed at similar depths and in similar physical relationship to the stream at all stations. Usually they are placed about 1-foot beneath the surface or 1-foot off the stream bed. The multiple-plate sampler can be reduced in size to three plates only and placed vertically near the surface, at mid-depth, and near the bottom at a particular station. Loss of some substrates because of vandalism or flooding should be anticipated.

Periphyton include that assemblage of organisms that grow on free surfaces of submerged objects in water and cover them with a slimy coat. Cooke (1956) comprehensively reviews the literature on the subject. Periphyton play an important role in flowing waters because these organisms are the major primary producers in that environment. Thus, they are an important part of a lake or reservoir study of both the influent and receiving streams. A number of substrates have been proposed with which to study attached organisms including glass slides, cement blocks, wooden shingles, and plexiglass plates (Grzenda and Brehmer, 1960). Growths on such substrates may be analyzed qualitatively or quantitatively.

The type of artificial substrate employed to collect organisms is not terribly important as long as the same type is used at all such sampling stations in a particular investigation. Any type will be somewhat selective in those organisms that are attracted to it. They do tend to favor drift organisms or those that become detached from their dwelling areas and float downstream with the current. When the same type of sampler is used at each station, data collected among the stations should be comparable.

Patrick et al. (1954) developed a slide-carrying device, termed the Catherwood Diatometer, to sample the diatom populations of streams. It consists of a plastic base mounted on a lead bar shaped like a boat. On the plastic base are mounted two floats designed so that the depth to which the diatometer is sunk can be varied. Between the floats, behind a

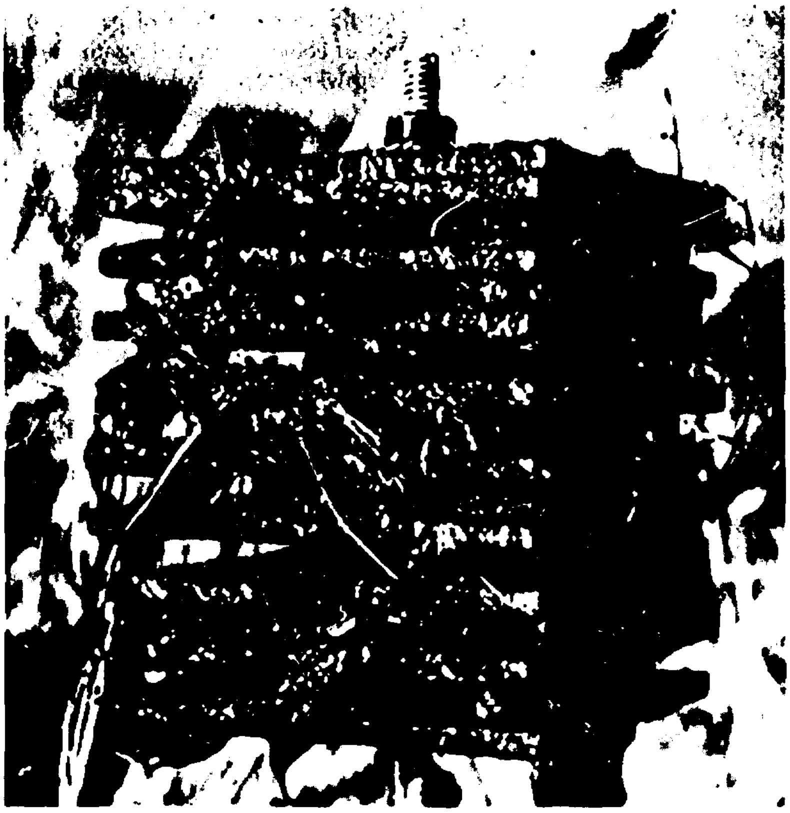

Figure 16. A multiple-plate artificial substrate colonized by aquatic organisms (Hester-Dendy type).

plastic V-shaped vane, the plastic slide holder slotted to hold six slides vertically is mounted edgewise to the current. The vane prevents excess washing of the slides. It was stated that 1 week was sufficient to expose the slides and that the population of an unpolluted stream could be estimated as adequately with this method as with the usual methods of collecting diatoms. Calculations upon which these estimates are based must be corrected when dealing with polluted streams.

A comprehensive review on limnological methods to investigate periphytic communities has been prepared by Sladeckova (1962). She lists 448 references as a bibliography and portrays a large number of devices on which attached organisms can grow and be sampled. In a summary she states that there is no single, universal method for the quantitative evaluation of periphyton for every purpose. An analysis of ecological factors influencing the periphytic community may make methods for the evaluation of this community on natural substrata preferable. On the contrary, the

use of artificial substrata is essential for the determination of periphyton formation on a unit area or for the study of colonization and stratification of attached organisms, especially in deep water. The choice of exposure technique is often determined by circumstance. The duration of exposure must be tested in advance. Lund and Talling (1957) completed an earlier review with 777 references; they also discussed methods with special reference to algae, both planktonic and attached. Sladecek and Sladeckova (1964) discussed the glass slide method for the determination of periphytic production in particular. Methods were cited for the calculation of production rates.

In the study of attached organisms in waters receiving acid mine drainage, it was found that extreme corrosion of the slide holding device contributed to a substantial loss of samplers during the study period. A type of putty (Plasti-tak*) has been found to be extremely useful to secure microscope slides to clay bricks or to the upper fiber board plate of a multiplate sampler (Thomas, 1968). Advantages to this procedure include good holding power, noncorrosive aspects in acid or salt water, ease of artificial substrate placement, low cost, and removal of single slides without disturbing adjacent ones. The surface to which the adhesive is applied must be dry and clean and the adhesive will release in fast water after about 3 weeks.

To obtain a history of sediment deposition or to permit selection of strata within the sediments, sampling of these by a commercial core sampling device is expedient. Much information can be obtained of a historical nature and can be related to the problem under investigation through the chemical and biological examination of sediment cores.

Samples collected for plankton analysis are most often similar to those collected for the analyses of chemical water quality. They may be collected with the aid of a Kemmerer sampler or similar device that permits capture of a sample from a particular water strata.

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical current applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they commonly can be returned to the water uninjured.

The electrofishing unit may consist of a 110-volt, 60-cycle, heavy duty generator, an electrical control section, which is a modified commercially sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts a.c. and 25 to

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350 volts d.c. The a.c. current acts as a standby for the d.c. current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

Meaningful samples of littoral vegetation may be difficult to secure. Sampling, per se, is often not necessary. It is usually sufficient to map, identify, and estimate abundance of the principal components of the aquatic vegetation population.

Comprehensive investigation of particular field problems may necessitate special investigative tools that can be developed through modification of existing tools. The development and use of these devices depends in large measure on the ingenuity and imagination of the investigator. Special studies that may be performed in conjuction with a field investigation would include the conduct of bioassays to test organisms in particular effluents or other substances where toxicity to aquatic life may be suspected. The procedure to conduct bioassays is well described in Standard Methods for the Examination of Water and Wastewater (Anon., 1965).

Sample Analyses

For a detailed discussion of the laboratory examination of biological samples, Standard Methods for the Examination of Water and Wastewater should be examined.

When samples are collected of animals associated with the lake or stream bed the organisms and debris are usually preserved with 10 percent formalin. The formalized sample is washed in the laboratory to remove the strong formalin solution. From this point it is necessary to remove and segregate the animals on which an interpretation will be made from the debris within the sample jar. A number of flotation methods have been proposed by various authors to reduce the time expended in this operation. When an investigation includes stream reaches that are heavily polluted with organic sludges or that produce prolific growths of slimes and other attached organisms, flotation methods do not work well. Thus, as a routine measure the somewhat laborious effort of separating organisms from debris through hand sorting must be employed.

A white enamel pan with a depth of approximately 1½" is often used in the hand picking operation. It is convenient to half fill the pan with water and then place 2 or 3 tablespoons of material from the sample jar in the center of the pan. By teasing the sample to all sides with the aid of forceps, small animals can be removed without difficulty. It is helpful for later indentification to keep the removed organisms separated into the taxonomic groups that are discernible with the unaided eye. When it is noted that organisms within the collected sample are limited to a few (2 to 4) kinds and are extremely abundant as they often are when sludgeworms reproduce in great numbers in organic sludge, samples may be split to reduce time and labor in removing organisms. This is accomplished by placing the sample in the white pan without water, leveling the sample

surface, and randomly selecting 1/2, 1/4, 1/16, or 1/32, of the sample for organism removal. When this is done, the entire sample should be examined for those larger organisms that may not be numerous. In reports written principally for those outside of the biological discipline, bottom faunal abundance is expressed usually as the number of a particular kind of organism per square foot. Organisms from a 6" x 6" Ekman dredge sample, for example, would be multipled by 4 to arrive at the number per square foot. When the sample is split and only an aliquot examined, the appropriate conversion multiplication must also be used. Further identification through the use of a stereoscopic microscope and counts to ascertain numbers within a particular group are made to facilitate interpretation of water quality.

Slimes and other attached growths are identified and estimates made of relative abundance. Quantitative methods are often employed. Chlorophyll determinations may be used as an indicator of those plants that possess this material and the determination is often helpful to separate attached algal quantities from slimes.

Chlorophyll, an enzyme present in green plants, in the presence of light converts carbon dioxide and water to basic sugar, a process that is termed photosynthesis. Chlorophyll increases in lakes as the lakes become more eutrophic; thus chlorophyll measurements provide comparative data on

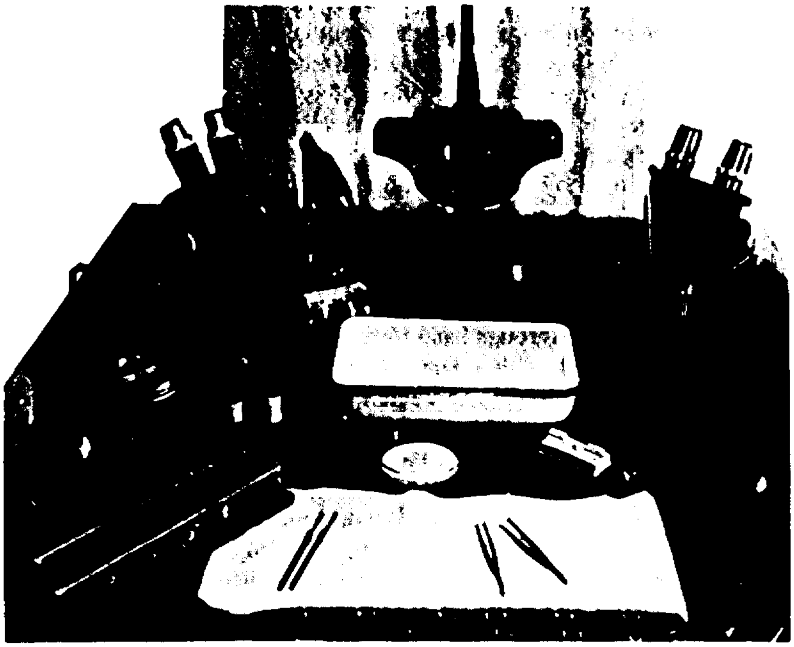

Figure 17. Sorting, enumeration, and identification equipment used in analyzing benthic samples.

eutrophication (Deevey and Bishop, 1942; Kozminski, 1938; Manning and Juday, 1941; Anderson, 1961).

The quantity of chlorophyll has also been used as a general index of the quantity of algae present (Harvey, 1934; Riley et al., 1949; Tucker, 1949). Chlorophyll is related closely to primary production or the conversion of organic materials to living plant tissue (Manning and Juday, 1941; Ryther and Yentsch, 1957; Odum et al., 1958). Because a large quantity of algae may be present, but not growing, and conversely a small population of algae may exhibit a substantial growth rate, the quantity of algae may not be related directly to primary production. Factors such as light intensity, nutrient availability, temperature, age or viability of algal cells, and size of the cells influence the quantity of chlorophyll per unit of algae present (Odum et al., 1958).

Chlorophyll-bearing cells may be filtered from the water with membrane filters (0.45 micron pore). Filters and cells are placed in vials of acetone for extraction of the pigments and for solution of the filters (Creitz and Richards, 1955). Samples are then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone is examined on a recording spectrophotometer. Spectrums are evaluated and the quantity of chlorophyll determined as outlined by Richards with Thompson (1952).

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from most natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration because it is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400X or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50-mm. long by 20-mm. wide by 1-mm. deep. Since the total area is 1,000 mm.^{2}, the total volume is 1×10^{12} cubic μ, 1,000 mm.^{3}, or 1 ml. A "strip" the length of the cell thus constitutes a volume 50-mm. long, 1-mm. deep, and the width of the Whipple field.

Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not cxpedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml.} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of "strip" (mm.}^3)}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml.} = \text{avg. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton, unusually abundant, other procedures may be employed in conjunction with and related to counts obtained from the Sedgwick-Rafter cell.

Lackey (1938) used a drop counting method in his examination of Scioto River, Ohio, phytoplankton. In this method, the sample is first centrifuged and ". . . after thorough agitation by alternately sucking it in and spurting it out of the pipette, the exact number of drops was counted and a sufficient number of drops of the decanted portion was added, so that one drop of catch bore a definite relationship to the amount centrifuged." One drop of sample is put on a glass slide and a cover glass added; 5 low-power fields and 10 high-power fields are examined, and number of each species is recorded at the magnifications used. Enumeration is repeated on 3 such mounts for a total of 15 lowpower fields and 30 high-power fields.

No per ml = avg. no. per field × no. of fields per drop or per cover slip × no. of drops per ml ÷ the concentration factor.

The concentration factor = ml of original sample ÷ ml of concentrate × (100 — percent of preservative in sample).

Lackey's method has the advantages of including all organisms in the catch, simplicity and ease of manipulation, and instant use of the high power magnification where identification with the low power is questionable. Certain disadvantages are inherent in the method: (1) because water normally is used as a mounting medium enumeration must be accomplished relatively rapidly to prevent dessication and subsequnt distortion of organisms; (2) results are not sufficiently accurate when only one slide-mount is examined, thus necessitating preparation and enumeration of at least three or more slide-mounts; and (3) the investigator should be sufficiently familiar with plankton to rapidly identify and count the specimens encountered.

Application of the membrane filter method of plankton counting requires a vacuum pump, special filtering papers, and experience in deter-

mining the proper amount of sample to be filtered. Plankton in samples from waters containing substantial quantities of suspended matter such as silt may be difficult to enumerate by this method since, in the process of filtering, the suspended matter tends to crush the plankton or otherwise obscure them from view. However, the method has certain features that make it particularly adaptable for use on waters with a low phytoplankton and silt contents. Primary among these features, the method permits the use of conventional microscope lenses to achieve high magnification for enumeration of small plankton (the membrane filter retains very small organisms), provides relatively rapid processing of samples if the investigator is familiar with the procedure and the plankton, does not require counting of individual plankters to derive enumeration data, and increases the probability of observing the less abundant forms (McNabb, 1960).

The sample is filtered through a 1-inch membrane filter. The wet filter is removed and placed on top of 2 drops of immersion oil on a microscopic slide, and 2 drops of immersion oil are placed on top of the filter. The filter is air-dried at room temperature until clear (approximately 48 hours). A cover slip is added prior to examination.

When examined, the magnification and sampling field or quadrat must be of such size that the most abundant species will appear in at least 70 but not more than 90 percent of the microscopic quadrats examined (80 percent is optimum). Otherwise the field size or the amount of sample concentrated must be altered. The occurrence of each species in 30 random microscopic fields is recorded.

Number of organisms per milliliter = density (d) from table 4 $\times$ number of quadrats or fields on membrane filter $\div$ number of milliliters filtered $\times$ formalin dilution factor [0.96 for 4 percent formalin].

Plankton samples form the Madison, Wis., sewage treatment plant effluent diversion study (Mackenthun et al., 1960) were concentrated by settling with a liquid detergent and were counted by the drop technique. To concentrate the phytoplankton, 500 ml. of stream water were placed in 1-liter glass settling cylinders to which were added 20 ml. of commercial formalin to preserve the sample, and 10 ml. of a detergent to settle the sample. Sedimentation of the plankton was complete in 24 hours, after which the supernatant was carefully siphoned from the cylinder, and the concentrate was washed into 100 ml. centrifuge tubes. These were spun at 2,000 r.p.m. for 6 minutes. The supernatant in the tube was decanted and the concentrate was washed into screw-capped storage vials and brought to the nearest 5 ml. by the addition of 4% formalin and the use of a volume standard. In making the drop count, 5 low-power fields and 10 high-power fields were observed on this slide, and the magnification as well as number of each species of organisms was recorded. This procedure was repeated on 3 such mounts so that totals of 15 low-power fields

Table 4. Conversion Table for Membrane Filter Technique (Based on 30 Scored Fields)

Total occurrence	F%	d
1	3.3	0.03
2	6.7	0.07
3	10.0	0.10
4	13.3	0.14
5	16.7	0.18
6	20.0	0.22
7	23.3	0.26
8	26.7	0.31
9	30.0	0.35
10	33.3	0.40
11	36.7	0.45
12	40.0	0.51
13	43.3	0.57
14	46.7	0.63
15	50.0	0.69
16	53.3	0.76
17	56.7	0.83
18	60.0	0.91
19	63.3	1.00
20	66.7	1.10
21	70.0	1.20
22	73.3	1.32
23	76.7	1.47
24	80.0	1.61
25	83.3	1.79
26	86.7	2.02
27	90.0	2.30
28	93.3	2.71
29	96.7	3.42
30	100.0	?

$$\text{Where F} = \frac{\text{total number of species occurrences} \times 100}{\text{total number of quadrats examined}}$$

and 30 high-power fields were observed. The number of a particular type of organism in 1 liter of water was determined by the following formula:

$$\text{No./l} = \frac{(\text{Avg No./field})\ (\text{No. fields/coverslip})\ (\text{No. drops/ml}) \times 1{,}000}{\text{Concentration factor}}$$

$$\text{The concentration factor} = \frac{\text{ml. of original sample}}{(\text{ml. of concentrate})\ (0.94)}$$

where 0.94 accounts for the dilution of the sample by the addition of formalin and the detergent.

The average volume in cubic microns of each species was obtained by measuring 20 individuals. The volume contributed by each species was expressed in parts per million by use of the following formula:

Volume (ppm) = (No. org/l) (avg species vol in μ^3) $\times 10^{-9}$.

Palmer (Palmer and Maloney, 1954), developed a new counting slide for nannoplankton.

Mackenthun employed constable tubes to determine cell volume in a 1956 Wisconsin study. Concentrated algal samples were obtained on July 25, 1956, and again on August 8, 1956, from Station 1 in the Menasha Channel, Fox River, at mileage designation 38.5, at Station 2 from the Rapide Croche Dam at mileage designation 19.5, and Station 3 upstream from De Pere Dam at mileage designation 7.0. The concentrated algal samples were obtained by centrifuging 50 gallons of river water at 12,000 r.p.m. and suspending the residue in 1 gallon of algal-free water. A blender was employed in resuspending the algae. An aloquot sample of this 50 to 1 concentration was used for biological analyses.

Ten ml. of the concentrated samples, equivalent to 500 ml. of raw water, were centrifuged at an approximate speed of 2,000 r.p.m. in a constable tube. The addition of a small amount of detergent to the constable tube will facilitate the packing of small blue-green algae. On August 8, 50 liters of river water were strained through a fine plankton net at the 3 stations for comparative purposes. The cell pack or cell volume as calculated on a raw-water basis was as follows:

Cell pack (ml./1.)

Station	July 25	August 8 Centrifuged	August 8 Net plankton
1	0.068	0.086	0.071
2	.058	.066	.038
3	.036	.045	.031

Both the centrifuged and net plankton samples taken on August 8 displayed color stratification in the constable tube. The upper white layer was composed principally of single blue-green algal cells and small fragments of blue-green algal colonies. The middle light green layer was principally blue-green colonies and many celled filaments or larger fragments of these filaments of *Aphanizomenon*, *Anabaena*, and *Gloeotrichia*. In addition, there were numerous single blue-green cells and some colonial greens with a few diatoms. The lower dark layer was predominately blue-green algae, because of their abundance in the sample, but diatoms were heavily concentrated. The large-celled *Lyngbya birgei* was most concentrated in this layer, as was the dinoflagellate, *Ceratium*.

The packed cells, or residue, from the constable tubes were washed in distilled water and were dried and ignited in a platinum dish. The following results were obtained:

Sta.	Mg. dry Wgt./L 7-25C	Mg. dry Wgt./L 8-8C	Mg. dry Wgt./L 8-8N	Mg. Ash/L 7-25C	Mg. Ash/L 8-8C	Mg. Ash/L 8-8N	Mg. Vol. Sol./L 7-25C	Mg. Vol. Sol./L 8-8C	Mg. Vol. Sol./L 8-8N
1	9.8	14.6	11.8	4.4	6.8	3.0	5.4	7.8	8.8
2	10.6	14.4	8.6	5.4	4.6	2.0	5.2	9.8	6.6
3	4.8	6.4	7.2	2.0	2.8	1.2	2.8	3.6	6.0

C—Centrifuged sample N—Net plankton Vol. Sol.—volatile solids

Segments of lake bottom core samples may be analyzed microscopically to determine the diatom composition of the layered segments. To examine diatomaceous sediments in lake bed core sediments, an aliquot solids sample based on a packed volume of a selected core segment is oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) are added, the mixture cooled, washed into a centrifuge tube, and water added. The sample is washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue is then diluted to a specific volume of water (200 ml. per gram of original sample), then 2 drops of liquid household detergent are added, the sample is stirred, and 2 drops of sample are withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover slip is evaporated to dryness on a hot plate. Following drying the hot plate temperature is increased to 350° F, a clean microscopic slide is placed thereon, and a large drop of suitable microscopic mounting media such as Harleco* or Styrax* is placed on the slide. After 10 minutes, with slight cooling, the cover slip with the dried sample is inverted onto the mounting medium drop and pressed firmly into place. The slide is then examined for diatom skeletons.

Reporting

Reporting of the findings is equally as important as any other aspect of problem solving. A report represents the end product of the investigation. It is often the only link between the field investigation, which may take considerable time, money, and effort, and the public or particular report recipient. A report often recommends corrective actions to abate a problem, and these abatement efforts are necessary for the advancement of society. Thus, the report may be the most important part of a particular investigation, particularly because of the effect that it can have on broad political changes that may be focused on a problem area.

A report has certain basic yet essential features. The first of these is the title page, or cover, listing the author(s) and the responsible agency or where the report may be obtained. The title should not be too long but it should identify precisely the report contents. The second feature involves the summary, conclusions, recommendations and predictions, which are usually placed near the front of the report for ease in finding and value in display. The third basic component involves the report narrative, which includes the display of data, such as charts and figures and the discussion. The last is the report appendix.

The report *introduction* should describe briefly the problem and its location, the study objectives, the inclusive dates of the investigation, the authority for the study, and by whom the study was performed. It may re-

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late briefly the methods used to conduct the study, but generally such descriptions should be placed in the appendix, particularly when they are lengthy and include nonstandard ones. The introduction is often placed near the front of the report, and is followed by the summary.

The summary, conclusions, recommendations, and predictions may be the only parts of the report that are read by many of the report audience. These sections represent a condensation of the entire study; they should be drafted with great care.

When not preceded by the introduction, the first paragraph within the *summary* should introduce the study and should identify what was studied, where the study took place, who made the study and when, and what the study objectives were. The summary should briefly and concisely relate how the study was accomplished and what was found in the investigation. The entire summary should be as brief as possible and yet contain these essential facts. Stringent review and editing should always be employed. The summary should contain those particular facts that will be used to formulate conclusions. The language of the summary should be specific, and numerical data to substantiate or explain particular statements should be given where appropriate.

The *conclusions* should be concise, positive, lucid statements that relate what may be concluded from the summarized data and other observations. There is often a difference of opinion among report writers regarding the numbering of thoughts or paragraphs within the conclusions. From the standpoint of conciseness and adherence to a particular thought, it is helpful to number conclusions in consecutive order, at least initially. After these have been edited and re-edited the numbers may be removed without harm to the text material. Many writers prefer to retain the numbers. The report narrative and the data it contains must support the conclusions. The conclusions in turn must support the recommendations, and each recommendation should have a supporting conclusion.

Recommendations should be preferably numbered in consecutive order and developed with great care and sound logic. Recommendations represent the groundwork towards abatement or problem correction.

Predictions may or may not be within the investigation's objectives. They are of great value to the report's reading audience, however, to ascertain that water quality which is expected to be attained when all recommendations are met, when 50 percent or 30 percent of the recommendations are completed, or if no action is taken as a result of the investigation. Such predictions might well follow that section of the report devoted to recommendations.

The narrative within the report body supports the summary, conclusions, and recommendations. Its structure can be enhanced, and omissions avoided, by a carefully prepared outline listing all necessary items in logical continuity.

The *area description* section should include a general area location map, as well as a specific map of the study reach showing stations sampled, principal population centers and principal waste sources. Background information on municipal and industrial development and land use is helpful here.

The *water uses* section describes in informative detail those uses associated with:

(a) Municipalities,
(b) Fish propagation and production,
(c) Recreation,
(d) Industrial water supply,
(e) Navigation,
(f) Irrigation, and
(g) Hydropower.

Monetary damages resulting from existing or predicted water quality associated with these uses, and benefits from recommendations made should be noted where possible.

The *waste sources* section discusses wastes entering the waterway including:

(a) Municipal,
(b) Industrial, and
(c) Agricultural.

Measured or computed waste loads to specific stream reaches, with itemized particular wastewater constituents where possible, should be ascribed to each major waste source described specifically and separately.

The *effects of pollution on water quality and uses* include the findings of fact and their discussion, analyses and interpretation. This is the report section that bears the major burden of support for the conclusions and recommendations. Its principal discussions center around various water quality standards and specifically bacterial pollution, aquatic life in all its many facets, and aesthetic considerations. Featured within this section are data display and data interpretation.

Organizing the data entails graphs, photographs, and tables. Here a spark of ingenuity and imagination will reap great rewards. Often a report is "sold" by the manner in which data are organized and presented. Data first are arranged in tables. Lengthy, detailed tables should be placed in the report appendix—if placed in the narrative, they detract from reading coherency. Easy-to-follow summary tables, prepared as a digest of the tabulated data in the appendix, are helpful in the narrative to explain and substantiate discussion and conclusions.

Relationships among particular components within the data or trends among stream reaches of particular water quality components may be

shown as graphs. Graphs should be uncluttered, pertinent, and easy to follow. Broad lines to illustrate trends are preferred. Should the reader wish to verify a particular value at a given point, he will consult the detailed tables. Graphs should "picture" important information and be used sparingly only to underscore principal points.

In developing a report, do not say that certain information may be found in Table X or Figure Y, because this type of statement does not give the reader any vital information. Rather, make a positive factual statement using pertinent data within the sentence to substantiate the statement, and refer to the appropriate table or figure parenthetically as a source to substantiate the data used and to gain additional information. Interpret for the reader. Do not expect the reader to interpret tabular data or figures without help from the report narrative. It is always the readers prerogative to agree or disagree with the writer's interpretations.

Data interpretation gives meaning and vitality to the report. Interpretation is a clear statement of what is meant by what was found.

What is the problem?

Why is it a problem?

What is the cause?

What are the effects?

What corrections can be instituted?

Where should these be made?

When should corrections be initiated, and completed?

Data interpretation includes an evaluation of visible observations, of factors such as the physical drift of organisms into the sampling station from a tributary or an area unaffected by pollution, and of organism population trends throughout the study reach. Other studies often are cited to substantiate the writer's findings or to show that other investigators have found similar, or different, phenomena under comparable circumstances. Citations from other works should be adequately and correctly referenced. Unless the report is a literature search, literature citations should be reserved for important points that can be made more positive or more clear with additional clarification or substantiation from an outside source.

The report *appendix* is the proper recipient of long or complex tables, charts or tables listing scientific names, discussions of methods or procedures, descriptions of special studies performed to ascertain particular facts described in report narrative, and elaborate calculations. These materials should not detract from the reading of the report narrative by being placed within it.

An appropriate report cover should be designed that will wrap the package suitably to present to the reader.

The writer should read aloud his report to ascertain illogical approaches and flaws in rhythm. This procedure may be the greatest aid to

self-editing. Good technical writing is clear and concise and omits needless words. The specific word should be chosen instead of the general, the definite word instead of the vague, the concrete word instead of the abstract. Qualifying words should be avoided! Rarely is there more than one proper word to express a particular idea. A discriminate writer will search for that word, and when it is found he will profit thereby.

Finally the report should be submitted to an associate whose judgment is respected for review (Mackenthun, 1969). When a report is submitted to a reviewer, both writer and reviewer assume certain specific obligations. The writer should submit his report for review only after completing his own revision as discussed.

The writer has an obligation to inform the reviewer of the report's purpose and its expected audience. Is the purpose of the report to inform generally? To establish a specific fact in the literature? To establish policy? To interpret data? To serve as a basis for conference or litigation in resolving a particular problem? Will the audience be the general lay public, people technically trained in the report's subject, or will it represent a mixture of several technical skills and varied interests?

The writer is obligated to:

(a) Strive for the best in manuscript preparation, placing it in final form as talents permit;

(b) Be meticulous about data accuracy, grammar, punctuation, and spelling;

(c) Develop the report for the reading level of the report's audience;

(d) Forward a minimum of two manuscript copies to each reviewer —it may be desirable for the reviewer to retain one and return one with comments in the report margin to the writer; and

(e) Avoid writing down everything that has been done with the expectation that their viewer will cut, organize, and reconstruct the manuscript.

The writer should prepare himself mentally for critical review comments. Remember, the reviewer usually attempts at all times to be helpful and constructive. A "no comment" reviewer most likely has not fulfilled his obligation and is of no help to the writer.

A proper review entails consideration of the technical message, as well as the manner in which the message is presented. A review can be editorial only, but rarely can a technical review disregard the editorial aspects. Good grammer and technical competence usually are inseparable. A technical reviewer reads a document for clarity, technical accuracy, and to determine whether a dual meaning is present in the written word:

The reviewer is obligated to:

(a) Consider the purpose the report is designed to fulfill;

(b) Be constructive, thorough, and helpful with comments;

(c) Be certain of his own accuracy in suggesting changes;
(d) Base comments on the technical level and interests of report audience;
(e) Avoid sarcasm, argument, or destruction of the writer's style for the sake of expression in the reviewer's words; and
(f) Appreciate that the purpose of the review is to help the writer produce a better report.

Demonstrations

Following a field study with its report including conclusions, recommendations, and predictions, there is urgent need to ascertain the correctness and value of those recommendations and predictions. Assuming that the proffered recommendations are feasible technically and monetarily, their value should be demonstrated through appropriate action. Far too many studies are terminated with a report. Technical advancement can best be made by effecting sound and logical demonstrations to determine the correctness of particular recommendations and predictions. Through time, and using the investigative report and implemented demonstrations as a basis of fact, future investigators can adapt and modify their recommendations and predictions to answer future problems in an improved manner.

5

ORGANIC WASTES

USING selected portions of past field investigations as examples, it will be shown in this and succeeding chapters how various water quality constituents can affect aquatic life and how this type of information can be presented to those not intimately familiar with the biological discipline.

Menominee River

In early August 1963, a field study, limited to 12 days, was made on the Brule and Menominee rivers separating Michigan from Wisconsin.* The Brule River rises in northern Wisconsin near the eastern edge of a popular recreational area dotted with many natural lakes. It flows through Wisconsin in an easterly direction becoming the boundary between Michigan and Wisconsin. Downstream the Brule joins the Michigamme River to form the Menominee River, which continues as the states boundary flowing in a southeasterly direction for about 115 miles to the Menominee, Michigan-Marinette, Wisconsin, area where it enters the Green Bay arm of Lake Michigan (figure 18).

The Brule and Menominee rivers pass through a gently rolling, thickly wooded valley, which exhibits a restful scenic beauty. The virgin white pine forests of the valley, which once provided a major national source of white pine lumber, have largely been replaced by the attractive quaking aspen, interspaced with groups of a variety of conifers and an occasional hardwood.

The cool, swift waters of the upper reaches of the Brule River provide an ideal habitat for trout; the warmer waters of the Menominee support sturgeon, walleye, bass, bluegill, and other sport fishes. Between Florence, Wis., and the Memominee-Marinette area there are eleven dams that im-

* Report on Pollution of the Interstate Waters of the Menominee and Brule Rivers, Michigan-Wisconsin, by A. W. West, K. M. Mackenthun, L. E. Keup and F. W. Kittrell. U.S. Department of Health, Education and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, November 1963.

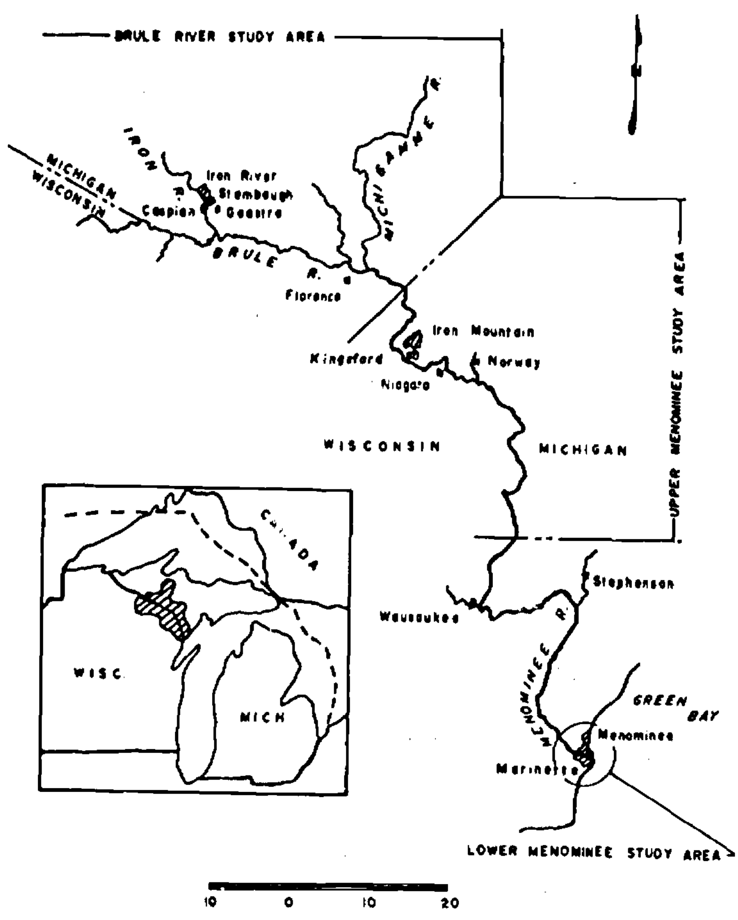

Figure 18. Location map for the Brule and Menominee Rivers, Wisconsin-Michigan.

pound run-of-the-river pools on the Menominee River. During the 12 days of the survey, the mean daily river discharges averaged 300 cubic feet per second (c.f.s.) at the mouth of the Brule River, 1,200 c.f.s. in the upper Menominee River and 1,400 c.f.s. in the downstream reaches of the Menominee. In addition to sewage effluent representing various degrees of treatment, the rivers received pollutants from important industrial operations including iron ore, pulp and paper, and organic chemicals.

The Brule River received from its tributary, the Iron River, the acid mine drainage from four iron mines and the effluents from four municipal sewage treatment plants. About 1 year prior to the study the Iron River had received gross acid mine drainage pollution.

The Brule River stream bed was composed of rock, rubble, and gravel with occasional sand. The current was swift and water depths ranged from 6 inches to 2 feet in areas sampled. Samples of stream bed associated organisms were collected in a 20-mile stream reach. Findings indicated that conditions upstream from the confluence of the Iron and Brule rivers were adequate to support a bottom organism community that is typically associated with unpolluted water including stoneflies, riffle beetles, mayflies, and caddisflies. Downstream from this confluence, many organisms sensitive to adverse conditions were reduced drastically in population while those organisms that were able to secure their food supply

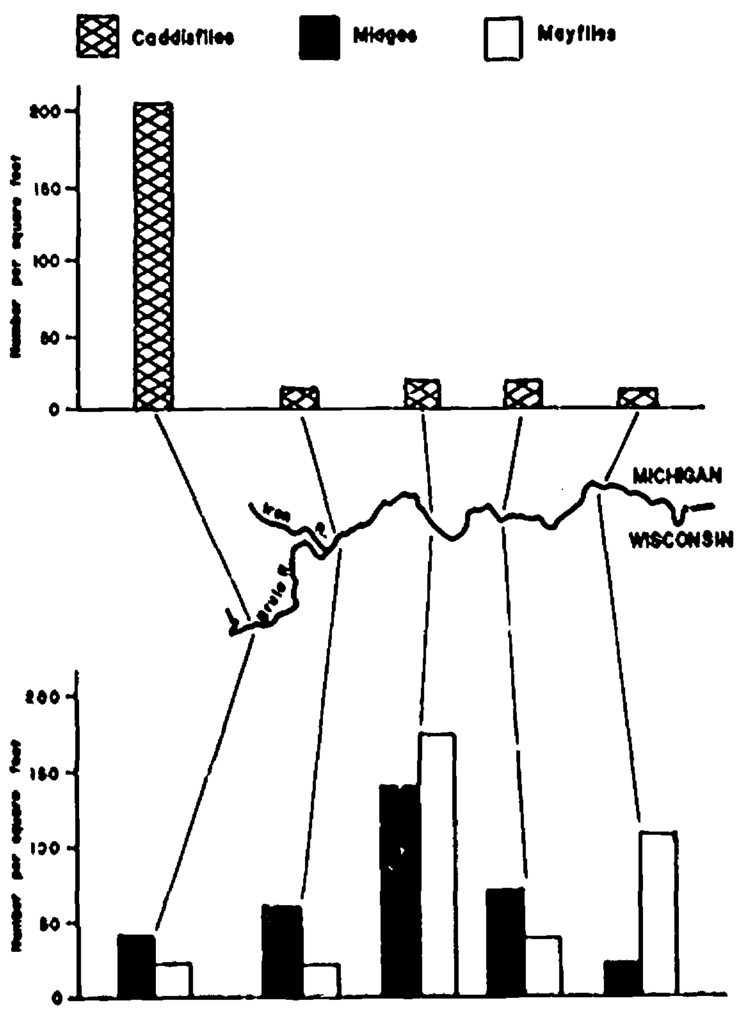

Figure 19. Populations of selected benthic organisms in the Brule River, 1963.

while living in close association with a dense growth of filamentous green algae prospered in numbers (figure 19).

In the Kingsford Iron Mountain, Mich., area, samples for bottom associated organisms were taken at river mile 96.4, 200 yards downstream from the sewage treatment plant, and in Upper Quinnesec reservoir at mileage 93.7 (figure 20). Upstream from the organic waste source, there was a balanced bottom dwelling community with many organisms sensitive towards pollution and relatively few tolerant sludgeworms or other organism types that tolerate and thrive in organic wastes (figure 21).

In the biological data display for this report, three very broad organism classifications were used. These consisted of those sensitive organisms including immature stoneflies, caddisflies, mayflies, riffle beetles and hellgrammites; those organisms very tolerant towards organic wastes including sludgeworms, several species of midges with ventral blood gills, the pond leech *Helobdella stagnalis* (Linnaeus), and worm-like organisms that are associated closely with this group; and a large group of organisms

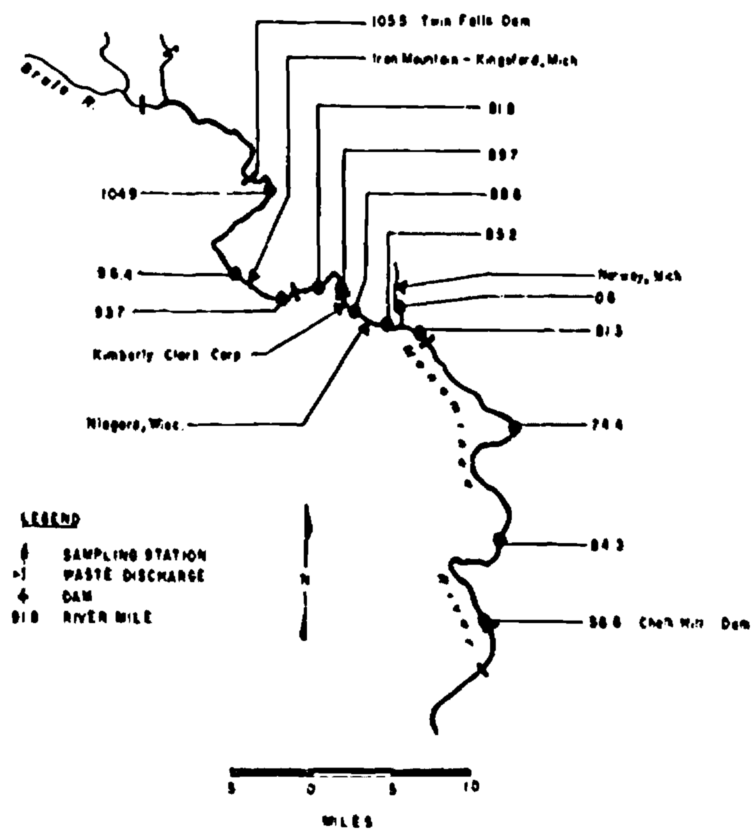

Figure 20. Sampling station location map for the Menominee River.

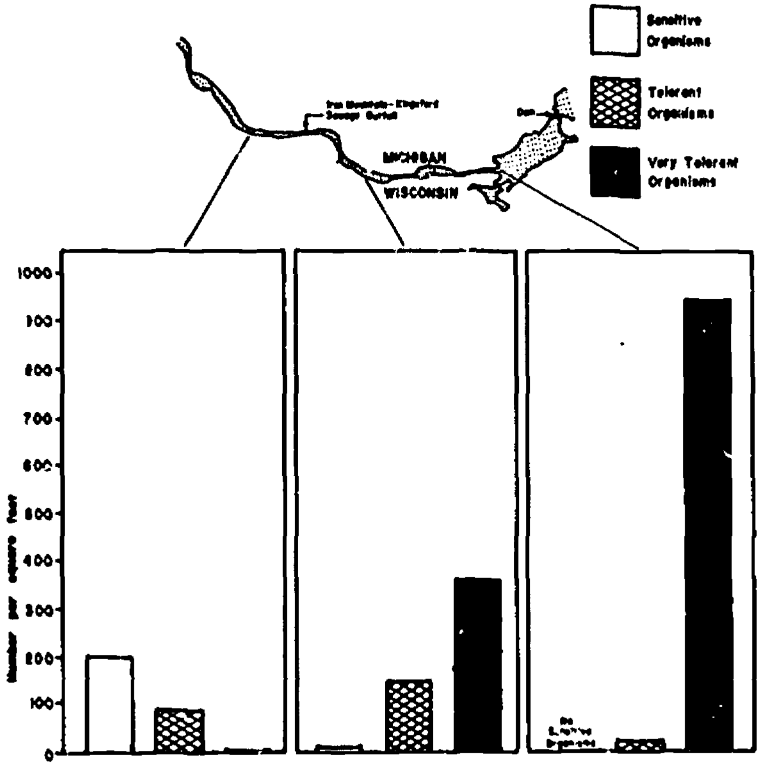

Figure 21. Bottom organism populations—Iron Mountain-Kingsford area, Menominee River, August, 1963.

that are termed tolerant because they are not now known to fit either of the other two groups.

The display of biological data in the aforementioned manner is very effective because the dramatic environmental change in the very few stream miles from a point upstream from the waste source to the uppermost reaches of a receiving reservoir is largely self-evident (figure 21). The clean water associated forms decreased from a plentiful population that would furnish food for an abundant fish population to zero in three successive stations. Likewise, pollution tolerant organisms increased at the same three stations from barely discernible numbers to 950 per square foot, which is representative of a waterway bed covered with organic sludge.

To ascertain effects on sluggish water environments from Niagara, Wis., area pollution, bottom samples were collected from two reservoirs bracketing the area at river miles 89.7 and 81.3 respectively (figure 22). The population of bottom associated organisms found in the uppermost reservoir was considered typical for a clean water environment with a well diversified organism complex containing caddisflies and mayflies. The or-

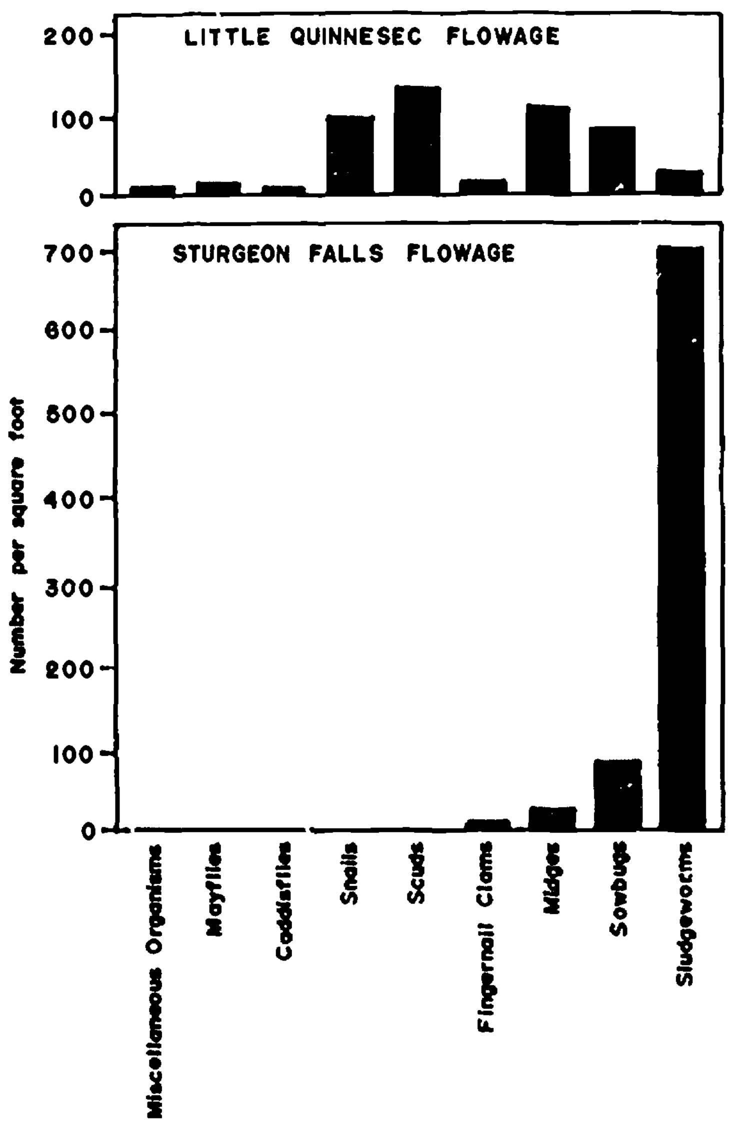

Figure 22. Comparison of bottom organism populations in two upper *Menominee River reservoirs.*

ganism assemblage in the Sturgeon Falls reservoir downstream was one depicting a polluted environment. Sensitive forms were eliminated; pollution tolerant forms were greatly increased compared to the upstream reservoir. Sludge and wood chips were found in areas of reduced current; wood fibers and slime bacteria were present.

Surber (1957) conducted a survey of lake reports and found that

". . . an abundance of tubificids in excess of 100 per square foot apparently truly represented polluted habitats." After more than a decade, this interpretative observation still seems sound.

That portion studied in the Lower Menominee River encompassed just slightly more than 3½ miles. An unpolluted environment was indicated at the upstream sampling station where sensitive burrowing mayflies were plentiful (figure 23). Downstream from the first organic waste source a

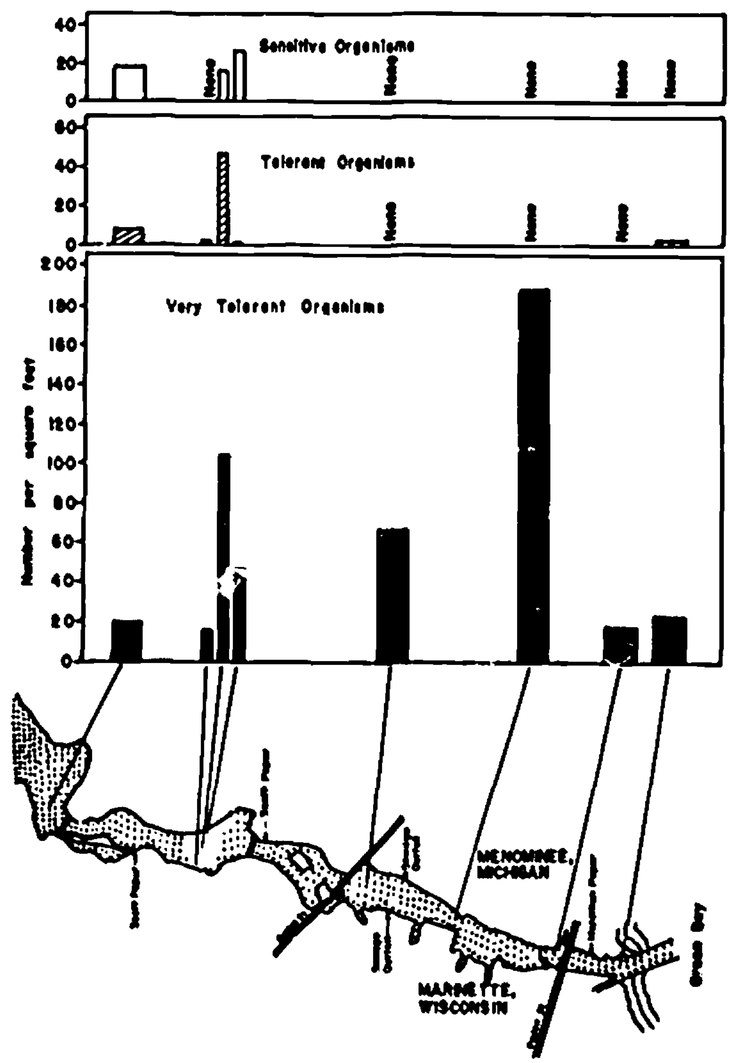

Figure 23. Populations of bottom associated organisms, lower Menominee River, August, 1963.

polluted habitat was found on the waste source side and a habitat only slightly defiled was found near the opposite bank, because of waste channeling in the receiving stream. Downstream from the waste source, sludge deposits, wood chips, wood fibers, and slime bacteria occasionally boiled to the surface as a mass, creating an unsightly and odoriferous condition, gradually dispersing and sinking at some point downstream to reform a sludge deposit and extend, physically, the zone of active decomposition.

When pulp and paper wastes had become fully mixed with the receiving waters, sensitive clean water organisms were eliminated from the polluted habitat as were those in the intermediate tolerant group. Only the pollution tolerant sludgeworms and bloodworms were found among wood chips, fibers, and slimes. The population of these increased downstream from sewage treatment plant waste sources, but decreased markedly downstream near the river's mouth because of toxic components within the sludge.

It is to be noted that in figures 19, 21, 22, and 23, biological data are presented clearly and concisely, and in a form that a layman can understand readily. The figures are not cluttered with too much detail and the bars in graphs are broad and easily distinguishable one from another to permit easy recognition of population trends and broad, significant differences among sampling areas. Data depicted for a particular station represented the average of samples taken at that station.

Blackstone River

The Blackstone River begins in the southern part of Worcester, Massachusetts, and flows in a southeasterly direction for 42 miles to Pawtucket, R.I., then southerly for 7 miles to its mouth at the Seekonk River. Principal tributaries include the Mumford and West Rivers from Massachusetts, and the Branch River from Rhode Island. Water quality data were obtained from field studies conducted during March and August, 1964.*

The Blackstone River drains an area of 540 square miles; its fall averages about 10 feet per mile. Formerly it tumbled over many rocky rapids, but these have long been buried beneath impoundments to create power. The first use of the water power of the Blackstone took place in 1671 and by the early 1700's many grist and sawmills were furnished power by low head dams in the basin. Some of these dams have been abandoned, but more than 50 still exist.

The most significant types of wastes in the Blackstone River drainage area are municipal sewage and woolen textile wastes. At the time of the survey, the river was receiving biochemical oxygen demanding sewage

* Report on Pollution of Interstate Waters of the Blackstone and Ten Mile Rivers, Mass.-R.I. K. M. Mackenthun, A. W. West, R. K. Ballentine, and F. W. Kittrell. U.S. Department of Health, Education, and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, January 1965.

wastes from a population equivalent to 93,000 persons. Forty-three percent of this organic load was introduced where the stream was relatively small near its headwaters, and where wastewater impact on aquatic life would be expected to be most noticeable. Recreational use and all fishery pursuits were severely limited because of organic pollution.

The suitability of the Blackstone River to support aquatic life at the time of the study was dramatically illustrated in figure 24 and 25 where the low organism diversity in upstream reaches corresponded with high populations of pollution tolerant organisms, principally sludgeworms. Near the river's headwaters, sludge deposits, oily substances, and slime growths supported over 20,000 sludgeworms per square foot. The sludge worm population increased in numbers following the introduction of sewage treatment plant wastes and then gradually decreased downstream as stream self-purification took place. Before the population could be diminished to a reasonable level (less than 100 per square foot) another source of organic waste was introduced to boost again the sludgeworm population. At river mile 22 (figure 25) a tributary carrying variously colored wool fibers and other materials introduced toxic materials into the Blackstone River that reduced bottom organism populations. Extensive sludge deposits, floating balls of fibers that were microscopically identified as being wool impregnated with grease, and slimes on bottom materials were observed.

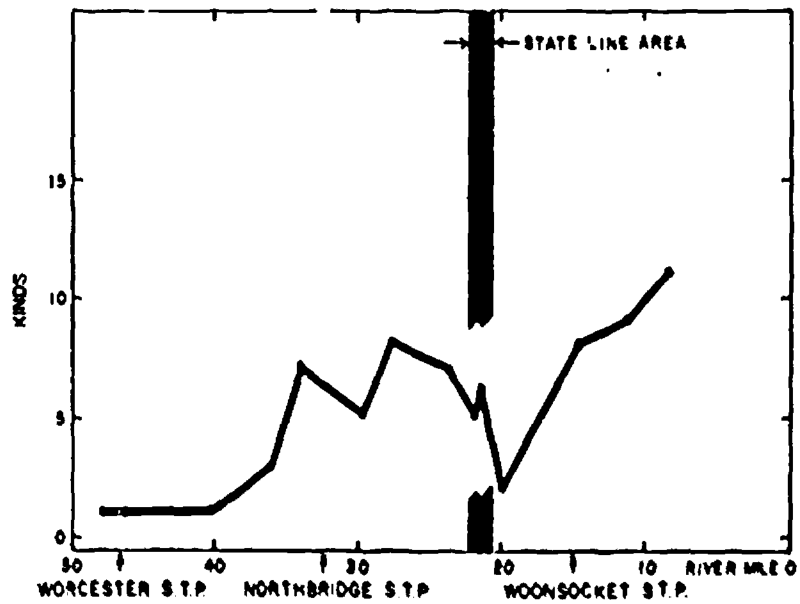

Figure 24. Kinds of bottom organisms, Blackstone River, August, 1964.

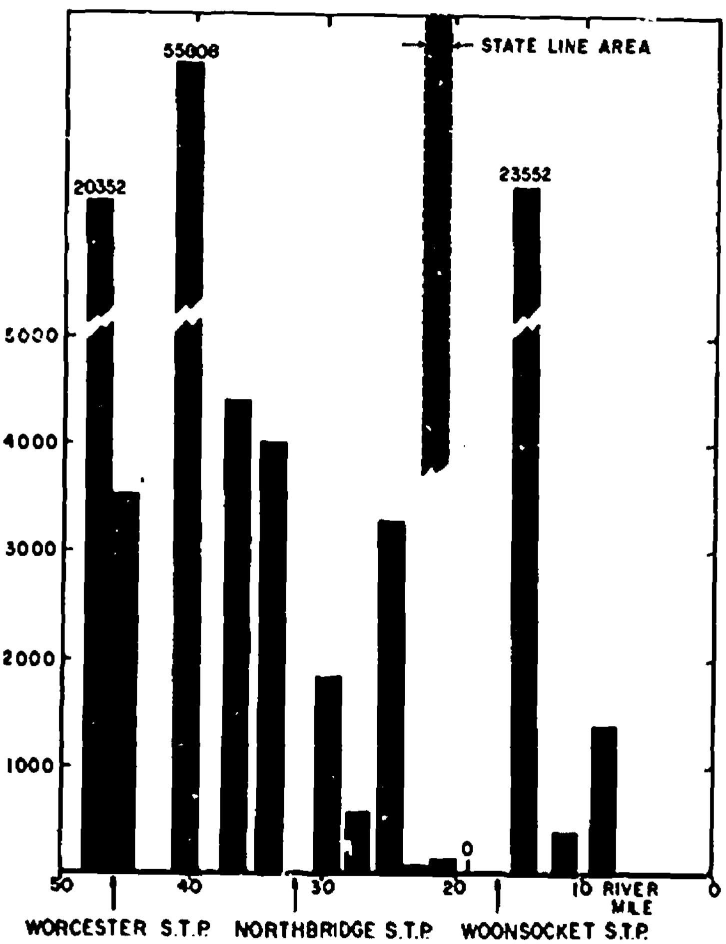

Figure 25. Numbers of pollution-tolerant bottom organisms per square foot, Blackstone River, August, 1964.

Wisconsin River

An intermittent 11-year biological study of the stream bottom life of the Wisconsin River, Wis., indicated no marked differences in bottom conditions at a given station among any of the years under investigation.* Prolific growths of filamentous bacterial slimes occurred in several stream reaches during both summer and winter periods. Unsuitable bottom habitats for organisms were created because of severely decreased dissolved oxygen and the blanketing effects of settleable solids and bacterial slimes. The area studied extended from mile 360 to mile 190 (figure 26).

* Mackenthun, K. M. 1961. The Impact of Pollution Upon Stream Biota in the Wisconsin River. 19 pp., mimeo.

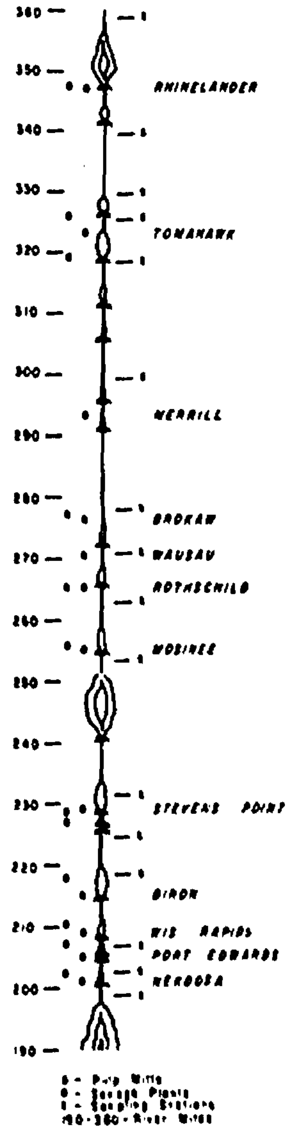

Figure 26. Wisconsin River profile with mileage designations, pollution sources, and sampling stations.

The long-term average flow for the several stations of record on the Wisconsin River is shown on the dilution chart (figure 27). The 50 percent duration value for the section under consideration ranges from slightly less than 1,000 c.f.s. at Rhinelander to slightly more than 3,000 c.f.s. at Nekoosa. Other things being equal, a given load discharged to a stream

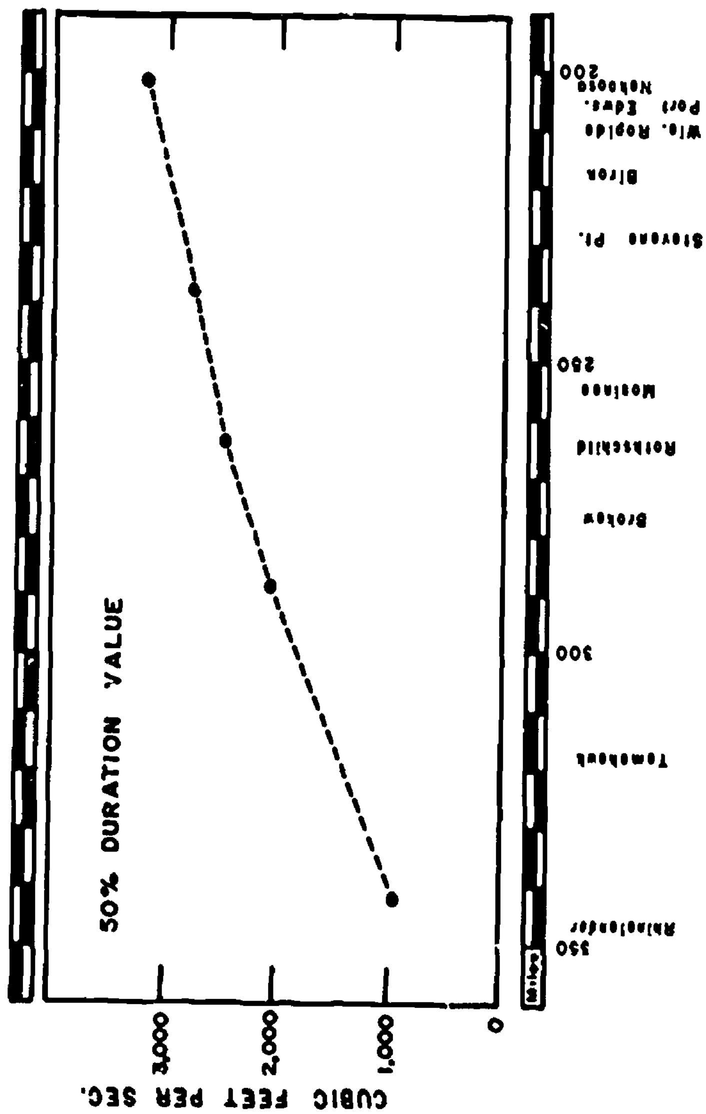

Figure 27. Wisconsin River Dilution Chart

having, for example, a 2,000 c.f.s. flow has the same degradation effect as one-half of the hypothetical load discharged at a point in the stream having only 1,000 c.f.s. flow.

Stream bed samples were collected both in August and in March under ice cover. March data indicate no intolerant (sensitive) bottom fauna downstream from Rhinelander, Wis., for a distance of about 50 miles

(figure 28). A similar paucity of sensitive organisms existed downstream from Brokaw for a distance of about 45 miles. Along with the species abundance shown as the number, the relative population abundance in number per square foot and the population characteristic shown as the percentage of the population abundance were depicted in this chart. Much can be said for such a presentation from the standpoint of careful interpretation of graphic materials, but the presentation is somewhat cluttered with too much detail and is difficult for the general reader to follow. Indeed, the August data were presented in similar fashion for 5 years for the entire river reach studied and the results of this presentation attempt precluded suitable reduction to picture here.

In general, the March biological data showed a slight reduction in bottom organism species abundance and some reduction in the population abundance. There was a general tendency to have a greater proportion of the population comprised of very tolerant forms. Especially in the areas upstream from Merrill and Brokaw, a reduction was noted in both species number and population abundance of the clean water forms. These two areas were influenced by the effects of upstream pollution during the winter months with a subsequent growth of filamentous bacteria that covered the bottom formations. Consequently, these areas fluctuated between periods of degradation in the winter and recovery during the summer. Thus, sampling beneath the ice in late winter showed that the zone of active decomposition had moved downstream from the source of organic pollution during winter. A stream reach that appeared unpolluted during summer supported growths of *Sphaerotilus* and associated bacteria with a reduction in sensitive organisms during winter.

A slightly earlier (1958) effort to display some of the same data was even more complicated, graphically (figure 29). A tremendous amount of data are shown in this figure: Stream mileages, major cities, location of dams, location of pulp and paper mills, organism numbers, percentages of sensitive, tolerant, and very tolerant organism numbers, zones of pollution, and variations among 4 years of sampling! Depicting the stream zones of pollution has merit for public interpretation providing sufficient explanatory material is presented. But, it is difficult, if not impossible, to present so much information graphically in clear understandable fashion on one page–interpretation would be challenging even to the professional.

South Platte River

Wastewaters entering the South Platte River in Denver, Colo., are of mixed origin.* They come from municipal treatment facilities, industries,

* From "Effects of Pollution on the Aquatic Life Resources of the South Platte River Basin," South Platte River Basin Project, Denver, Colo., and Technical Advisory and Investigations Branch, Cincinnati, Ohio, Federal Water Pollution Control Administration, U.S. Department of the Interior, December 1967, prepared by Lowell E. Keup.

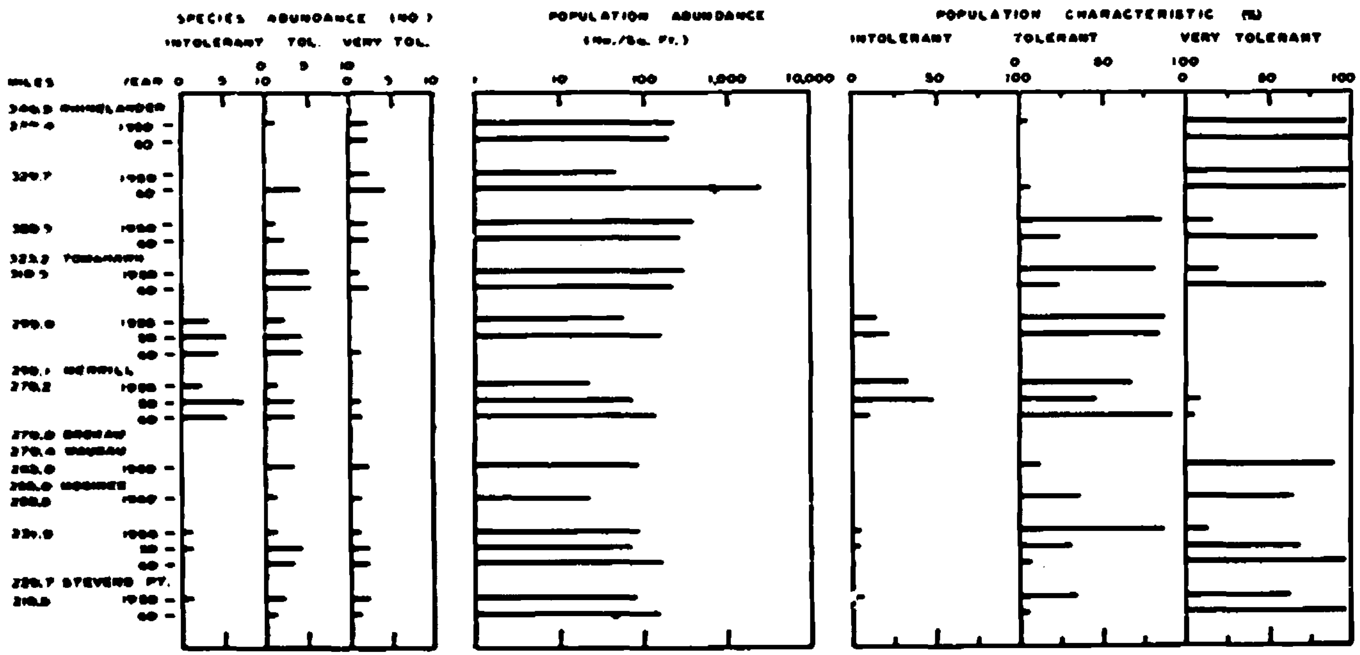

Figure 28. Wisconsin River bottom fauna—March data.

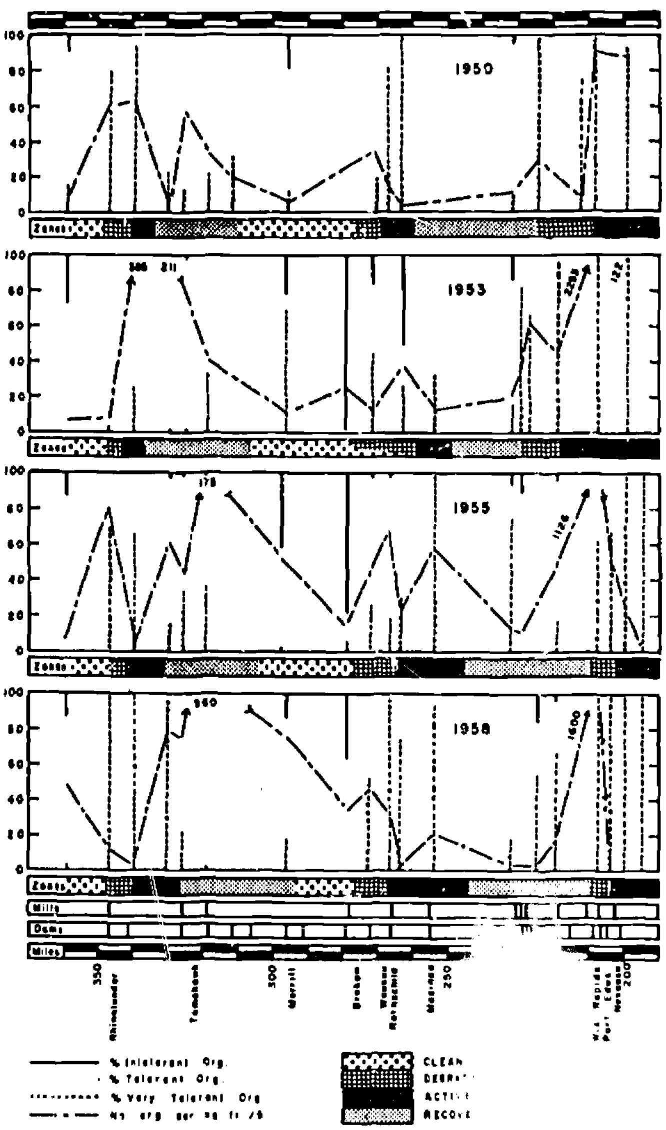

Figure 29. Biotic conditions in the Wisconsin R ugust.

cattle holding pens, storm sewers, and polluted tr major pollutant is organic solid materials, both suspended ther pollutants are present, but their effects are masked l derant organic materials.

Excessive quantities of organic wastes, underg decomposition, alter the chemical characteristics of the wat ucing large

quantities of sulfides, methane and other products of decomposition, and by reducing the quantity of dissolved oxygen. The settleable solids settle to the stream bottom forming organic rich sludgebeds that "blanket" the original bottom of gravel, rubble, or soil thereby altering the physical environment. These chemical and physical changes are not tolerated by sensitive organisms such as the aquatic stages of stoneflies, mayfies, and caddisflies, that are found in unpolluted habitats. Surviving pollution tolerant animals, such as sludgeworms, bloodworms, leeches and sewage flies increase in numbers because of a lack of competition from the eliminated forms. Sludgebeds may produce a large increase in numbers because they increase the habitable area and the available food for these "aquatic manure worms." Pollution may become so severe that even these relatively tolerant forms may be reduced in numbers or eliminated. Figure 30 illustrates the elimination of sensitive bottom animals and the rapid increase in the population of pollution tolerant organisms in May as the river enters the city of Denver. In August, 1964, near the confluence of Cherry Creek and at Platteville sludgeworm numbers were 38,000 and 19,500 per square foot, respectively.

During May and August, from the York Street bridge downstream to Fort Lupton, Colo., pollution by decomposing organics was severe enough to reduce pollution tolerant organisms (figure 30). At Franklin Street, the large quantity of decomposing organic material sufficiently lowered water quality so that even pollution tolerant organisms were eliminated. Here, the stream bed was covered with sludges, estimated at 45,000 tons wet weight, which were obviously rotting cow manure and undoubtedly originated from the cattle holding pens along this river reach.

After flowing 40 miles, the river recovered enough to allow large numbers of pollution tolerant sludgeworms and bloodworms to reappear in the bottom sludges at Platteville, Colo. (figure 30). In August large red patches of sludgeworms (19,500 per square foot) could be seen here on top of the sludge deposits. Filamentous slime growths were less extensive than they were upstream. Within a short distance from Platteville, much of this polluted water was diverted for irrigation and the areas downstream from here were influenced more by pollution from local sources than from the Denver Metropolitan Area.

East Pearl River

A diverse population of bottom fauna was found in the East and West Hobolochitto creeks and in Farr's Slough upstream from pollutional effects from Picayune, Miss., on the East Pearl River.* At one station, more than 40 species of bottom fauna were found (figure 31). Down-

* From Report on Pollution of Interstate Waters of the Pearl and East Pearl Rivers, L.-Miss., U.S. Department of Health, Education, and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, and Region IV Office, Atlanta, Ga., September 1963.

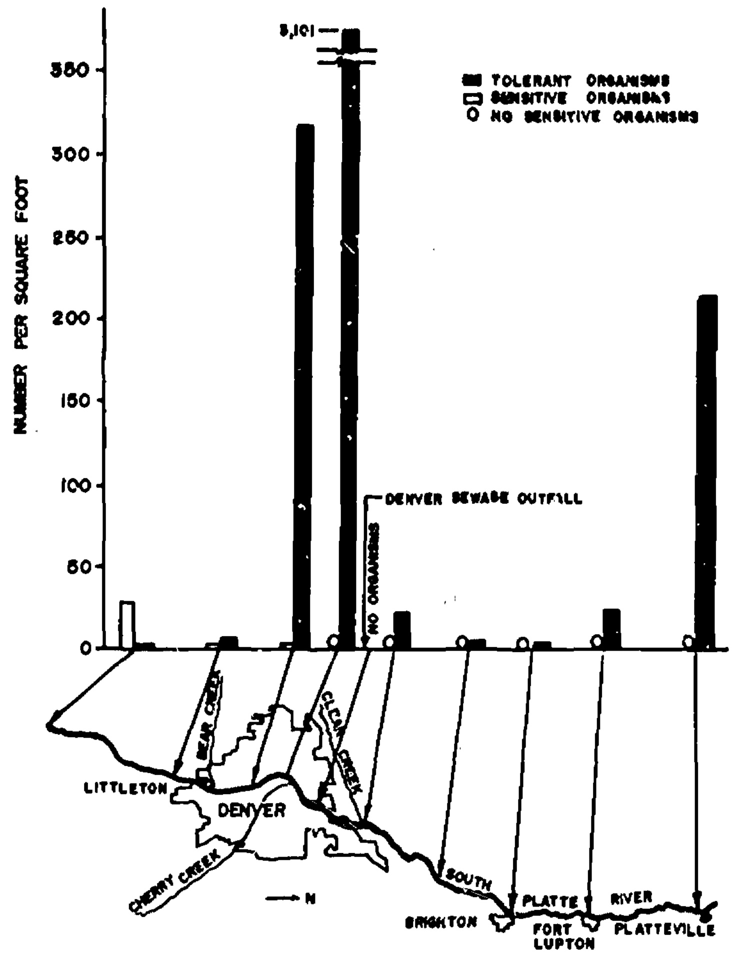

Figure 30. Populations of bottom animals, South Platte River, Denver Metropolitan Area, May, 1964.

stream from Picayune, and the discharge of a chemical company, biological samples showed distinct adverse effects from pollution on the stream bottom. Species numbers were reduced to four in this reach compared to upstream reaches where more than 10 and often 20 species were found. Pollution tolerant sludgeworms and blood worms increased here, sensitive mayflies and caddisflies were absent but were plentiful at upstream stations, and bacterial slimes were obvious on higher aquatic plants and other supporting objects. The stream recovered rapidly and samples from stations downstream indicated a fauna rich in diversity again.

In late September, 1962, the chemical company discharged wastes toxic to aquatic life and a severe fish kill resulted that extended for at least 17

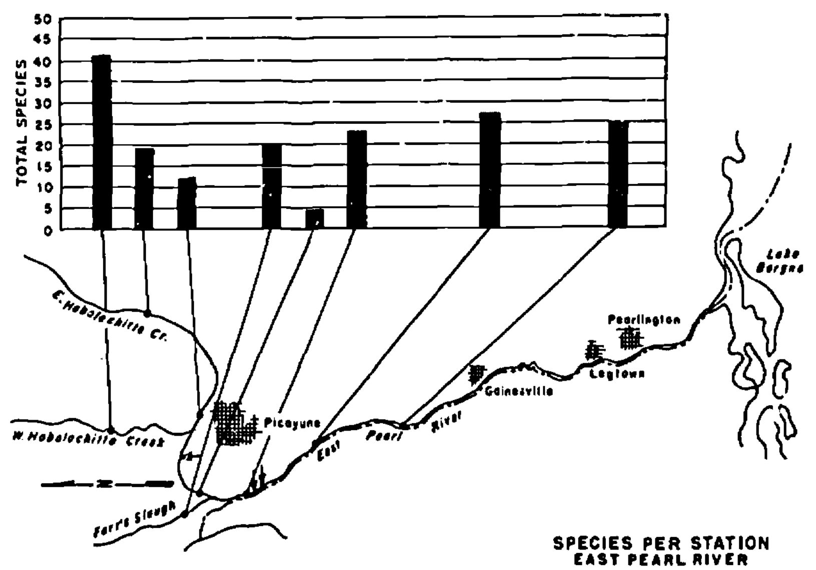

Figure 31. Species of bottom fauna per station, East Pearl River, 1962.

miles. Gar, game fish, minnows, eels, mullets, and even sturgeon were killed. Most of the bottom dwelling animals were also killed in the affected area. Where before there were four species found upstream from Picayune, none was found soon after the chemical release. At the subsequent three downstream stations, 23, 26, and 25, species were found at each station, respectively, prior to the chemical release and these included stonefly naiads, mayfly naiads, caddisfly larvae, hellgrammittes, and the more tolerant associates. After the chemical release that caused the fish kill, nine, five, and three species were found at these stations, respectively. Surviving organisms included a pulmonate snail, bloodworms, beetle larvae, tolerant damselfly and dragonfly naiads, and sludgeworms at one station. Toxic materials are considered in greater detail in Chapter VII.

6

SILTS

Coosa River System

THE Coosa River, formed by the confluence of the Etowah and Oostanaula rivers in Rome, Ga., flows westerly across Georgia into Alabama (Figure 32). Etowah River investigations began just downstream from Allatoona Dam near Cartersville, Ga.; they extended downstream to the confluence with the Oostanaula River in Rome, Ga., and continued in the Coosa River to Lake Weiss, Ala.*

Process wastes from mineral, chemical and textile industries, and raw domestic sewage were discharged to the Etowah River in the vicinity of Cartersville, Ga. During the August survey, silts from mining operations were carried downstream into the Coosa River and across the Georgia-Alabama State line.

In the upstream Etowah River study reach, flow was 300 c.f.s. for about 17 hours of the day; it climbed rapidly to a 7,300 c.f.s. peak at 12:15 p.m. and subsided again for the next 6 hours according to Allatoona Dam turbine operating schedules. Just upstream from the mouth of the Etowah River, flows ranged from 700 to 4,500 c.f.s. Flow in the Oostanaula River in Rome normally ranged between 800 and 1,000 c.f.s. except for an early morning low when the water surface elevations at the mouth were influenced by peak Etowah River flows. The more regular undulating flow pattern in the Coosa River reflected the combined flow characteristics of both the Etowah and Oostanaula rivers and ranged from about 2,000 to 4,600 c.f.s. diurnally.

The dominant pollution discharged to the Etowah River was silt. One ore processing company discharged 500 tons of mineral washing waste solids per day to the river a short distance downstream from Allatoona Dam. Other sources of silt pollution included road bank erosion and soil erosion.

* Report on Coosa River System, Georgia-Alabama. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, January 1963.

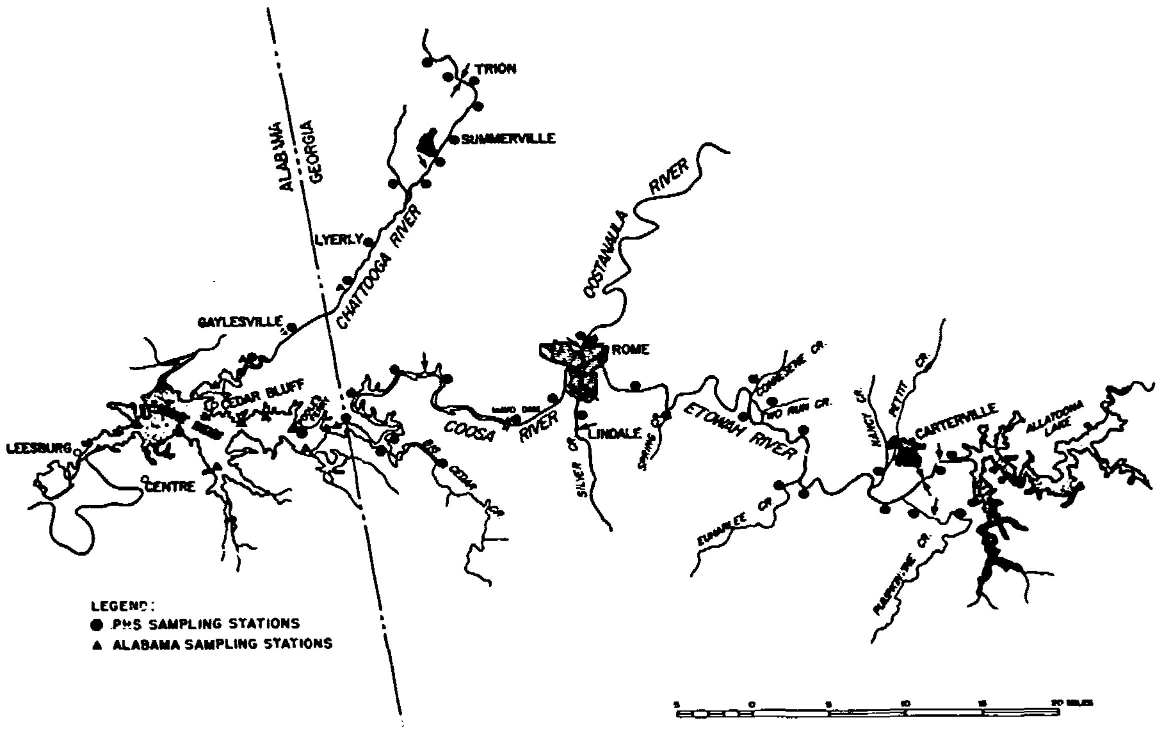

Figure 32. Location map and sampling stations on Coosa River system, Alabama-Georiga.

The color and turbidity in the Etowah River increased sharply around 11:30 a.m., about one-half hour after the turbines in Allatoona Dam were opened. During the next hour, stream suspended solids increased to 900 mg./l. peaks, and the color turned deep reddish-tan as most of the waste solids, which had been deposited the previous evening, were resuspended and flushed downstream. The suspended solids concentration subsided from about 12:30 a.m. to 2:30 p.m. and remained at or below 25 mg./l. during the next 20 hours of the daily cycles. The arithmetic average from 120 samples in a 24-hour suspended solids concentration study was 52 mg./1.; this calculated to 550 tons of suspended solids per day (figure 33). The entire Etowah River downstream from Allatoona Dam and the Coosa River to Lake Weiss were kept highly turbid because of their silt pollution.

A study of stream bed organisms indicated that deposition of silt and other particulate materials on the stream bed affected the quantitative and qualitative distribution of the benthos. The processes of erosion or of mining debris deposition increased greatly the relative proportion of finer materials in the stream bed and reduced the number of usable habitats in which organisms may live. These deposits were principally inorganic, and the combined impact of deposition and the abrasive action of the sand carried by strong currents was so great that the characteristic population response to organic wastes discharged at several points was not observed, except in the reach just downstream from Rome, Georgia.

Only a few organisms, mostly sludgeworms and midges, were able to survive in the silt-laden Etowah River (figure 34). The penstock discharge, deep in Allatoona Reservoir, was very low in dissolved oxygen resulting in a bottom organism population restricted to a very few tolerant forms. *Crenothrix* and other iron bacteria deposited a reddish-brown floc over much of the vegetation and portions of the near shore stream bed. A short distance downstream, the silty mineral washing wastewaters were discharged creating a restrictive habitat for most aquatic life. Limited numbers of sensitive organisms such as aquatic stages of mayflies and hellgrammites were restricted to the few remaining shallow riffles where the effects of silt pollution were least pronounced. The Coosa River also was very turbid and the population of stream bed organisms was only slightly enhanced over that found in the Etowah River. This study again demonstrated the adverse effects of silt and sand deposition upon the biota, both in restricting species diversity and also in limiting organism production to low numbers.

The three dimensional charts used to display the data in figures 34 and 35 are not well understood by the nonprofessional report reader; they should be used with caution. There is too often the tendency to display too much data on one page with confusion the result that ends in frustration and despair for the reader making the interpretation. As with most graphs, the three dimensional presentation is most effective to illustrate a

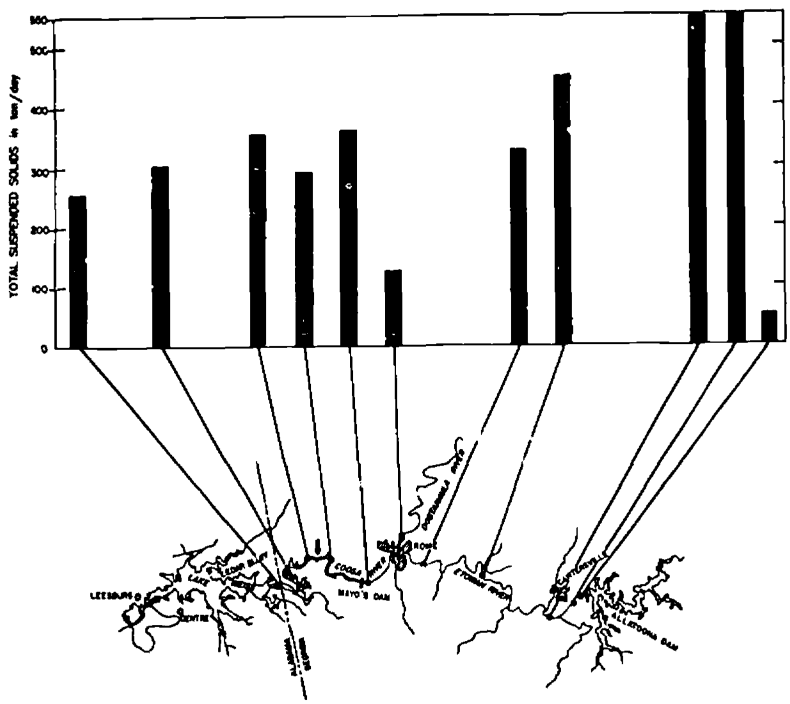

Figure 33. Total suspended solids in tons/day in Coosa River system.

minimal number of projections where trends can be noted easily without undue effort expended in interpretation. Figure 35, especially, does not meet this basic requirement.

Samples for planktonic algal determinations were collected from a depth of 2 feet at three locations in the Etowah River and four locations in the Coosa River (figure 35). A short distance downstream from Lake Allatoona, the waters in the Etowah River were very clear with 10 percent of the incident light remaining at the bottom in 60 inches. Planktonic algae had not had time to develop fully at this point. Five genera of algae other than diatoms and nine species of diatoms were found. Twenty-five miles downstream in the reach exposed to the effects of silt turbidity, the planktonic algal population was low (126 cells per ml.) and the genera of algae other than diatoms was reduced to two. Here, 1 percent of the incident light remained in only 26 inches of water. Because the algal population, which could affect light transmission through increased turbidity, was very low at this station, the low transparency was attributed to the inorganic silt load. The potential for algal development here was restricted to about 2 feet by the availability of light, and further was hampered by the adverse physical actions of sands and silts on algal cells.

The Oostanaula River, which joins the Etowah River at Rome, Ga.,

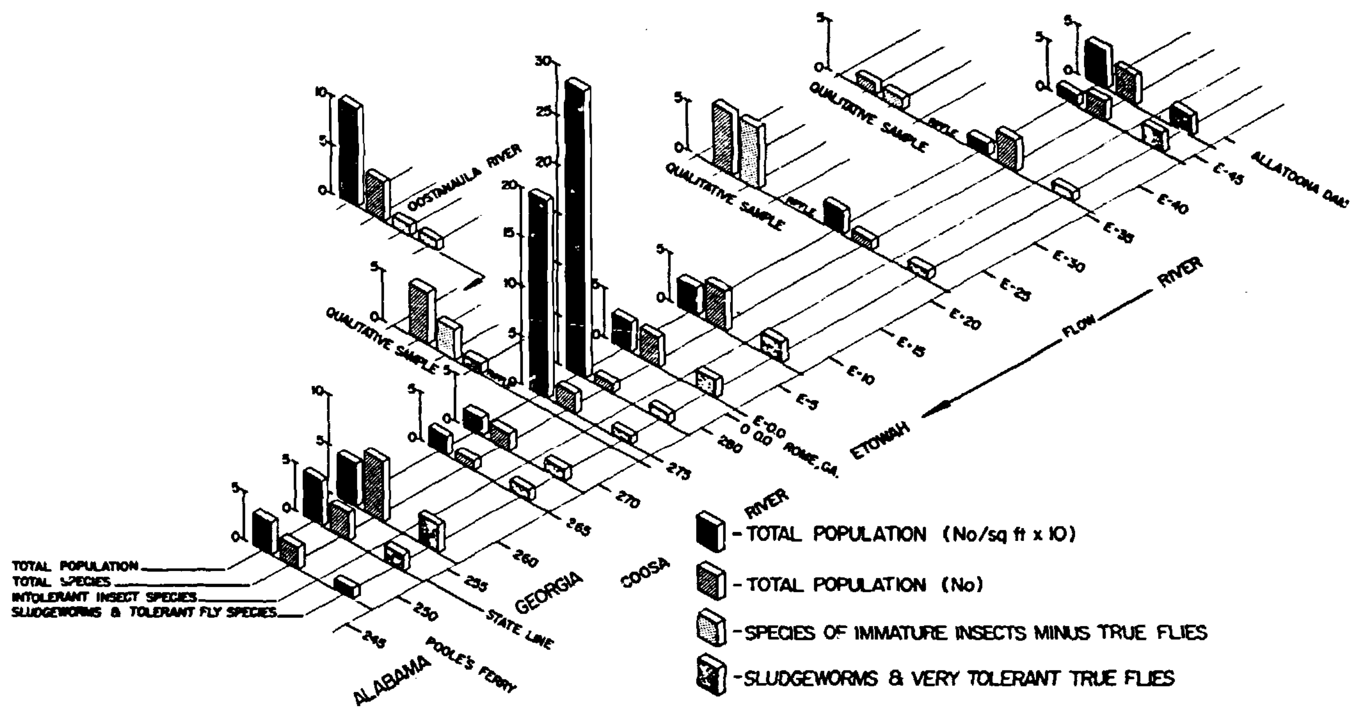

Figure 34. Population of stream bed associated organisms in Coosa River system, 1963.

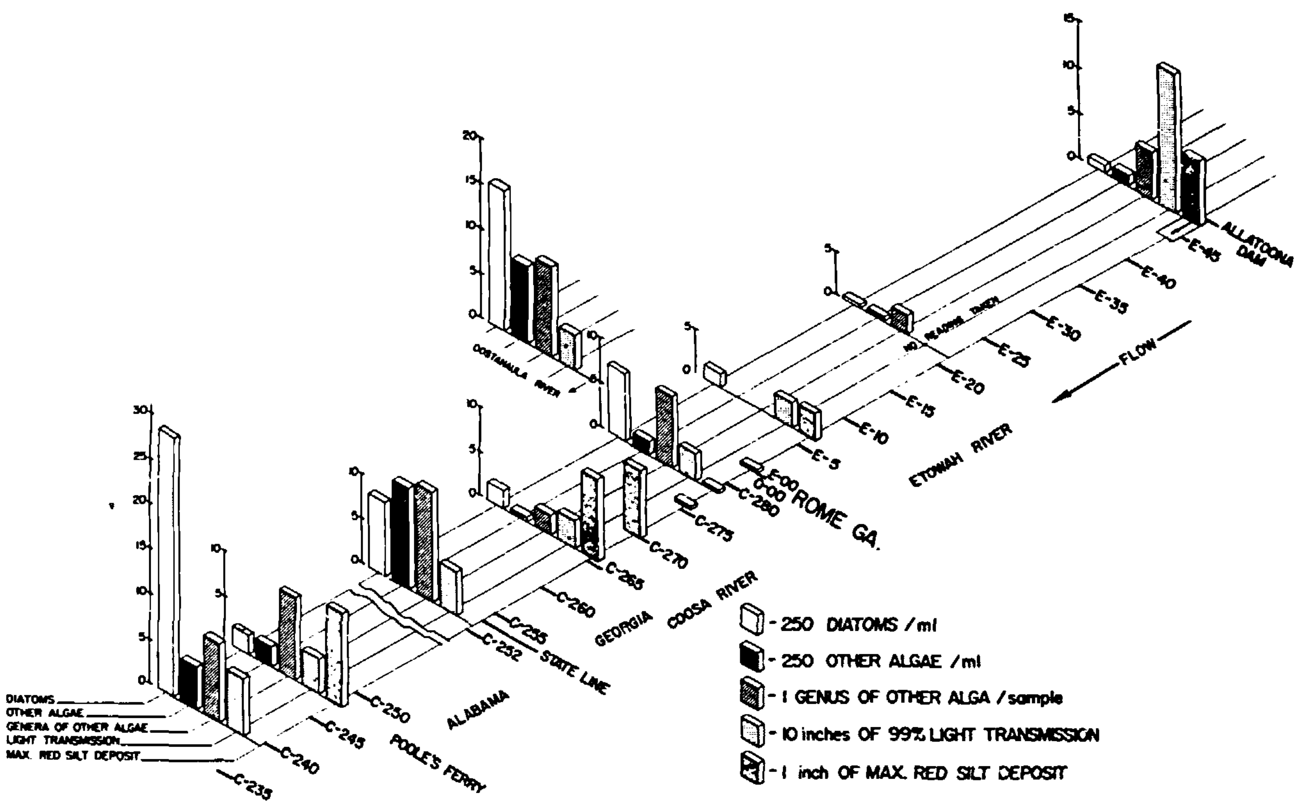

Figure 35. Algal population, light transmission and silt deposits, Coosa River system, Alabama-Georgia.

was used as a control environment unaffected by silt pollution other than land runoff. Here, the planktonic algal population was 10 times more abundant than at any place sampled in the Etowah River; 10 algal genera excluding diatoms were found.

Whenever possible, control stations should be located upstream on the same stream in which pollutional effects from waste sources are being observed. Occasionally this is not possible or practical as in the study of the Etowah River because of the presence of Lake Allatoona. In these cases, control stations may be selected on other streams within the same drainage basin and, as nearly as possible, with morphometric features similar to those of the study stream.

Light transmission was restricted in the Coosa River, and since the algal population was low, silt was the contributing factor. The depth of effective light penetration gradually increased downstream in the Coosa until at the State line 1 percent of the incident light, considered adequate for algal development, remained at a depth of 48 inches and 2.5 percent of the incident light, which is generally considered adequate for rooted aquatic plant development, remained at 37 inches.

Samples from a station near the center of Lake Weiss yielded the greatest algal population found during the survey (8,383 cells per ml.), as well as the deepest light transmission zone with 1 percent of the incident light penetrating to a depth of 65 inches.

Results of an electrofishing survey of 1-hour duration each on the Oostanaula River, the Coosa River 2 miles downstream from Rome, Ga., and the Coosa River near the State line were comparable with a similar number of game fish being observed at each station. Thus, no effects from silt on the catchable fish population were demonstrated by this investigation.

Observations indicated that heavier silts and sands continually rolled downstream in the Etowah River, temporarily settling above riffle areas and becoming resuspended immediately below them as the current pushed the particles over the riffles. This phenomenon produced a muddy water appearance below shallow obstructions in the main channel. Any type of current deflector in the center of the stream bed caused immediate settling of silt on the downstream side of the obstruction.

A thin layer of fine silt gradually settled into the bottom sand in the channel during times of low stream flow. At times of substantially increased flow, the silt is rolled up and resuspended from the sandy bottom by the force of the current, forming clouds of red water.

In regions of reduced stream velocity along the stream banks, and downstream from an inside meander, the silt settled and deposited on bottom substrates. A reduction in stream velocity also occurred in the upstream end of Lake Weiss with the resultant buildup of silt on the bottom of the flowage in the region of the old channel.

Results of core sampling of sediments deposited on the stream bed indicated a red silt layer 7-inches thick in the upper Etowah River reaches

and about 10-inches thick in the upstream backwaters of Lake Weiss. Barium, which occurred in the mineral ores but not in soil erosion sediments, was used to trace the deposition of mineral washing waste solids in the Etowah and Coosa Rivers. Barium was found in Etowah and Coosa River core sediments in concentrations ranging from 1.6 to 7.0 mg./g. dry weight and in the mineral washing sludge ponds in a concentration of 10.8 mg./g. It was not found in sediments taken from tributary streams.

Potomac River

The physical effects of inert inorganic solids in the Potomac River in 1952 have been described by Ingram and Towne (1960). Glass sand wastes were discharged to a stream that joined the Potomac River approximately one-half mile downstream. Upstream form this junction, the sparklingy clear Potomac was bedded with rocks, rocky ledges, coarse gravels, and some naturally occurring clean sand. Beds of *Elodea* sp. and *Potamogeton* spp. were plentiful. Gill-breathing snails and mayflies predominated in the invertebrate population, and were found everywhere on the bottom substrates. Large unionid, pearl-button clams were common marginally. Small fish were observed in abundance. Thirteen genera of bottom animals were represented in collections from this station (figure 36).

At a station 600 yards downstream, and on the same side as the confluence of the small creek receiving glass sand wastes with the Potomac River, the stream bed was devoid of visible animal life. Blue-green algae grew marginally on the wave-washed streambank areas. On the opposite side of the stream, 13 genera of animals were found in bottom samples, making the variation, displayed between the two sides of the stream, a dramatic presentation. From the affected bank to mid-stream, rocky ledges and bottom substrata of the original Potomac River were covered by a blanket of wasted glass sand fines up to 2-feet deep. It was reported that the effects of such deposits in 1958 were observed to suppress bottom organism abundance as far as 10 miles downstream. The displayed portion of the 1952 data (Figure 36) indicates the potential for stream recovery within a shorter distance.

Bear River and Tributaries

A study was made on the Bear River and tributaries, Idaho and Utah, in August and November 1962, to obtain information leading to the development of a pollution abatement plan and to indicate levels of pollution during the irrigation and bean canning season in August and the sugar beet processing and sauerkraut canning season in November.* A

* Survey of Interstate Pollution of the Bear River and Tributaries, Idaho-Utah, 1962. U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Water Supply and Pollution Control, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio, April 1963.

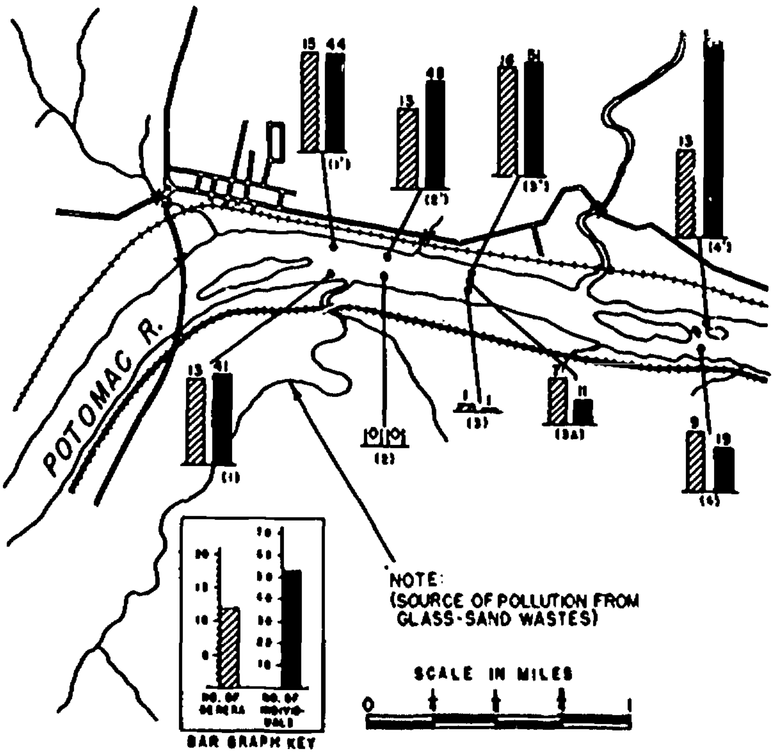

Figure 36. Genera and population numbers of bottom animals per square foot in Potomac River, September, 1952.

portion of the Bear River drains the Cache Valley lowlands where water is used to irrigate agriculture. The valley was interlaced with canals that transported water from reservoirs and stream diversion points to agricultural lands where is was applied. Ditches drained excess water from these areas and discharged it to natural drainage courses (figure 37).

Average monthly flows of 400 to 500 c.f.s. were the rule in the Bear River. During spring months, flows in excess of 1,000 c.f.s. may be expected, and in fall flows may fall short of the 400 c.f.s.

Ten stations were sampled in the Bear River from mile 99.5 to mile 51.8 (figure 38). In the two uppermost sampling stations, the stream bed was a long series of riffles interspersed with deep clear pools that offered excellent trout fishing. Here many different kinds of stream bed animals were found that formed a population of 400 per square foot.

At station 89.5, just downstream from Five Mile Creek (figure 37), sensitive caddisfly larvae and mayfly naiads were reduced and all of the remaining mayflies belonged to the genus *Tricorythodes*, which can withstand large amounts of silt. From this point downstream to Cutler Reservoir, the stream bed was silt-laden.

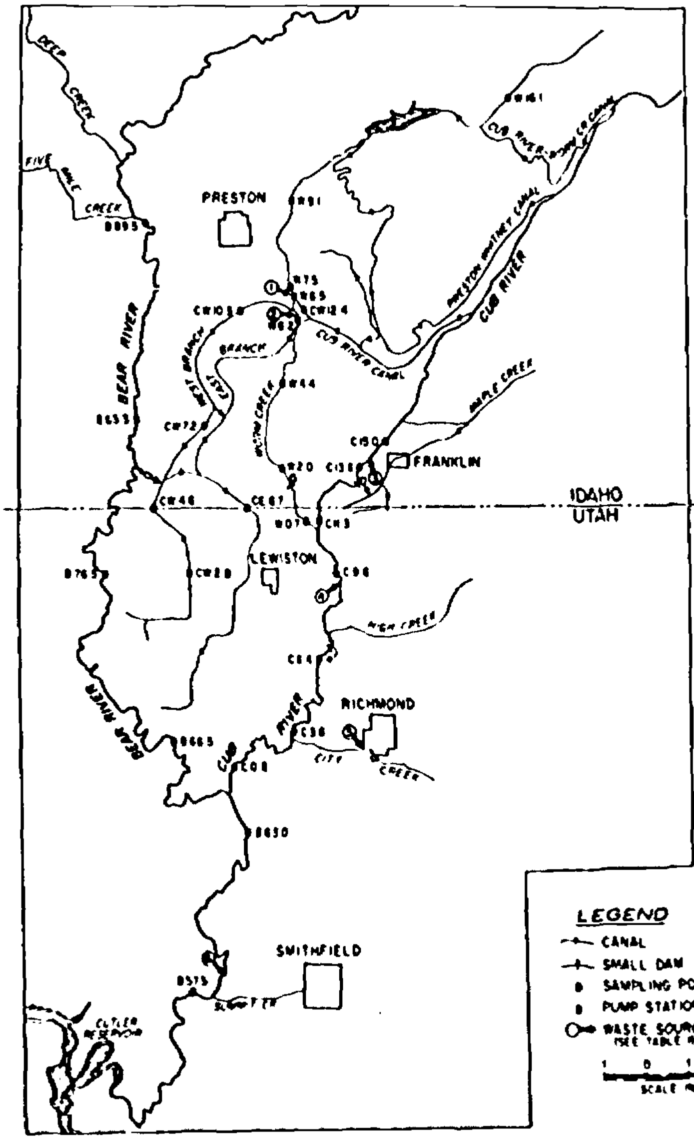

Figure 37. Bear River and tributaries drainage system.

Downstream only qualitative samples of bottom organisms, taken largely from rocks used in riprapping bridge approaches, could be obtained in August because of the sandy stream bed devoid of organisms. During the fall survey, artificial masonite substrates were used with a 3-week set. These were most successful in capturing a wide variety of

organisms with populations as high as 250 organisms per square foot including many intolerant mayfly naiads and caddisfly larvae.

Downstream from the entrance of organic pollution from the Cub River, there were no mayflies on the substrates in the fall and there was an increase in tolerant bloodworms. Also there was a growth of *Sphaerotilus* that practically covered the artificial substrate within the 3-week period of its set.

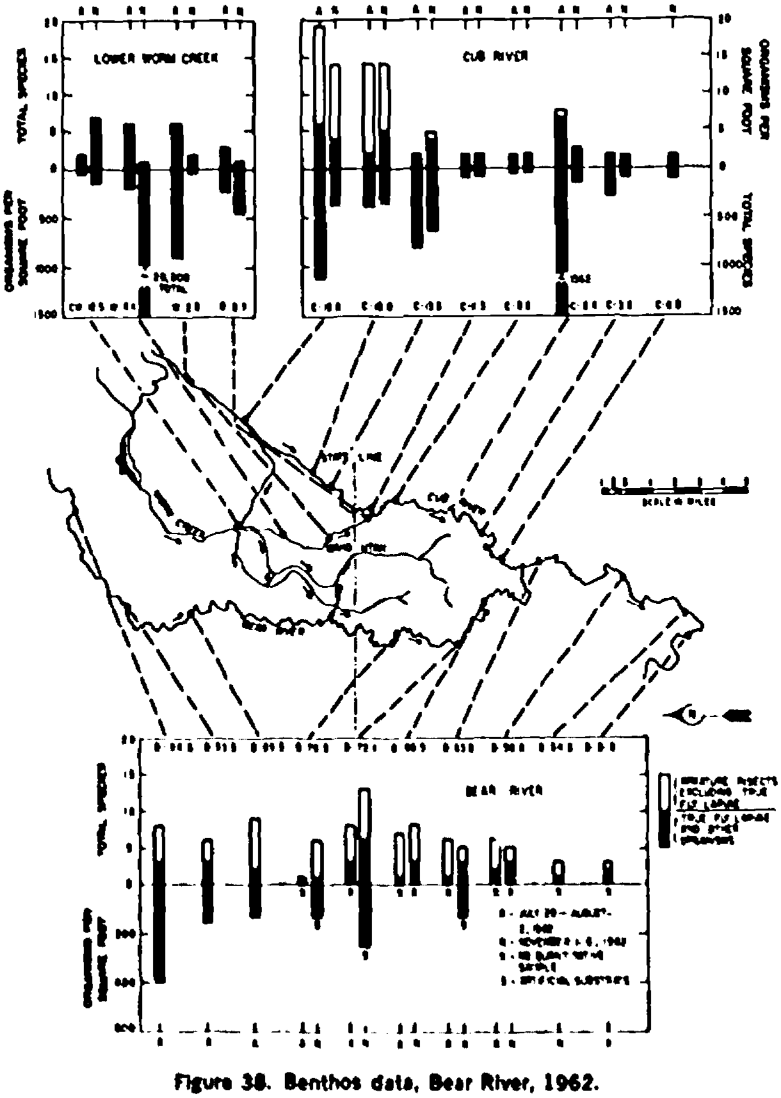

Figure 38. Benthos data, Bear River, 1962.

Stomach analyses of fish captured in this area showed that fish were feeding on the same types of organisms that were captured on the artificial substrates. Some of the individual stomachs contained as many as 15 caddisfly larvae and mayfly naiads. It seemed probable that the source of this fish food, and the source of the animals on the artificial substrates, was the highly productive riffle areas 30 or more miles upstream. Drifting mayflies have been reported as abundant as 170×10^6 *Baetis* sp. nymphs per day in large rivers (Pearson and Franklin, 1968).

It has been reported* that in the years 1910 to 1950, "The Bear River has deposited about 10 million tons of sandy sediment in its channel." This sand, 0.1 to 1 mm. in diameter, has been evenly deposited 5 to 6 feet deep over the natural gravel, clay, and silt bottom from Preston, Idaho, to Cutler Reservoir. It has come from gullies, drained by Five Mile Creek and Deep Creek, developed as a result of improper agricultural practices and poor land management. The deposited sand is of an entirely different character and origin than that of the original river channel; it not only covers the original stream bed, but also covers all but a few rocks along the river bank, thus further reducing available living spaces for organisms. Collected data on the Bear River indicate that stream bed animals were reduced from 400 per square foot in upstream natural areas to those few that were found on rocks near bridge abutments in the approximately 40 stream miles affected by sand intrusion.

Figure 38 is made somewhat unattractive as a form of data display chiefly because of the effort to show the location that each piece of data represented on a complicated stream flow system. The same graphs could have been used without drawing in the stream or using the connecting dashed lines, but, there is some advantage for data interpretation when stream locations can be viewed to gain mental perspective. The Bear River system does not lend itself well to this type of presentation because of its interlacing streams. Also, some may object to showing the number of organisms per square foot as projections below the dividing (0) line because their first impression, incorrectly, is that this represents a negative number.

Although there may be too much data displayed on one page, Figure 38 does permit the examination of the effects of more than one type of waste on stream biota. In addition to the silt pollution investigated in the Bear River, lower Worm Creek was polluted by sugar beet processing wastes. In August the stream was almost dry and the restricted flow was insufficient to permit stream recovery from the preceding fall. During fall, beet tops and pulp sludge exceeded 3 feet in depth in some stream reaches. Sludgeworms exceeded 20,000 per square foot. Only pollution tolerant organisms were found.

* Einstein, A. J. 1951. Preliminary Report on the Sedimentation in the Bear River Channel between Cutler Dam and the Preston Bridge, Utah, to the Utah Power and Light Company, Salt Lake City (Typed Copy).

The Cub River offered excellent trout habitat in its upper reaches. Its rock and coarse gravel stream bed here provided a habitat for many stonefly naiads, mayfly naiads, caddisfly larvae, and aquatic beetle larvae, as well as a hatchery for trout eggs and developing young trout. Just upstream from Station C–13.6 (figure 38), effluent from an industrial operation that canned peas, green beans, and sauerkraut entered the stream, and the Cub River became seriously degraded. For the following 14 downstream miles, the stream bed animal population was composed principlly of a few kinds of pollution tolerant sludgeworms, bloodworms, and leeches and occasionally large populations of these formed when water quality would permit.

7

TOXIC MATERIALS

Chattooga River

STUDIES on the Chattooga River* with a mean daily discharge of 94 c.f.s. began upstream from Trion, Ga., across the Georgia-Alabama State line and into Lake Weiss (Figure 32). Textile wastes and organic wastes entered the stream at Trion, Ga. and organic wastes, principally, entered at Summerville, Ga.

Water samples were collected daily for 14 days for dissolved oxygen determinations. Downstream from Trion, Ga., industrial and domestic wastes drastically reduced, and at times eliminated, the dissolved oxygen resources of the river (figure 39). This display of data is dramatic because a particular level or concentration of a water quality constituent could be chosen as an acceptable minimal criterion and the percentage of time that the criterion was not met was accentuated.

Discharged industrial wastes to the Chattooga River contained dyes in abundance. When river waters are polluted by dyes or similar wastes containing a variety of unnatural hues and colors, visual observations can often be more informative and provide a more realistic picture of stream appearance than routine comparison with laboratory color intensity standards. The color of the river downstream from Trion changed from day to day according to the type, volume, and intensity of dye stuffs included in the textile mill wastes. Changing from deep blue to black to brillant green, it faded to less intense shades of gray and green downstream.

During August 1962, 20 different kinds of stream bed animals, predominantly insects sensitive towards pollution were found in the rocks and coarse gravels upstream from Trion, Ga. Three miles downstream from Trion, no stream bed animals were found (figure 40). Only a layer of black sludge covered the stream bed. Industrial wastes were clearly toxic; and, they were present in sufficient concentration to eliminate the bottom animal community.

* Report on Coosa River System, Georgia-Alabama. Op. cit.

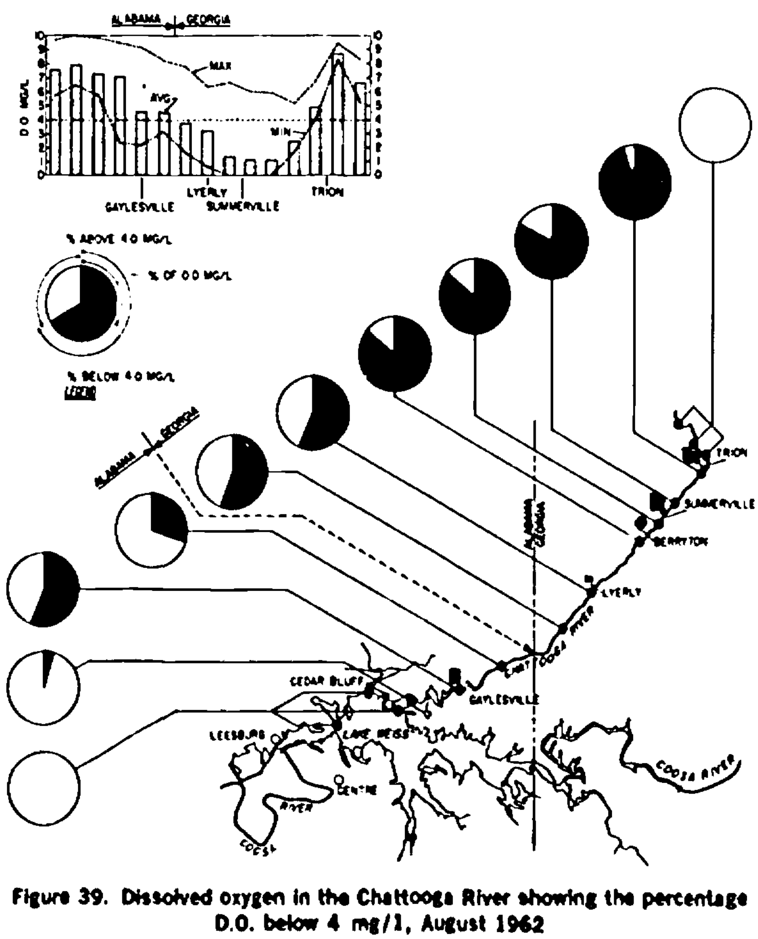

Figure 39. Dissolved oxygen in the Chattooga River showing the percentage D.O. below 4 mg/1, August 1962

Six miles downstream from Trion, stream bed conditions were only slightly improved. The settled sludge was less than 1-inch thick. Tolerant and very tolerant animals were predominant. A tolerant green alga, *Stigeoclonium* sp., adhered to bottom deposits.

Two miles farther downstream the green alga was still evident; filamentous blue-green algae and diatoms were able to tolerate the environment here and were attached to rocks. Sludgeworms, the only benthic organism encountered, survived the diluted toxic materials and responded to the food in the organic pollution producing a population of 680 per square foot.

After receiving toxic and organic wastes at Trion, Ga. the stream did not support a stream bed animal population indicative of unpolluted waters for a distance of about 22 stream miles. In the affected stream reach,

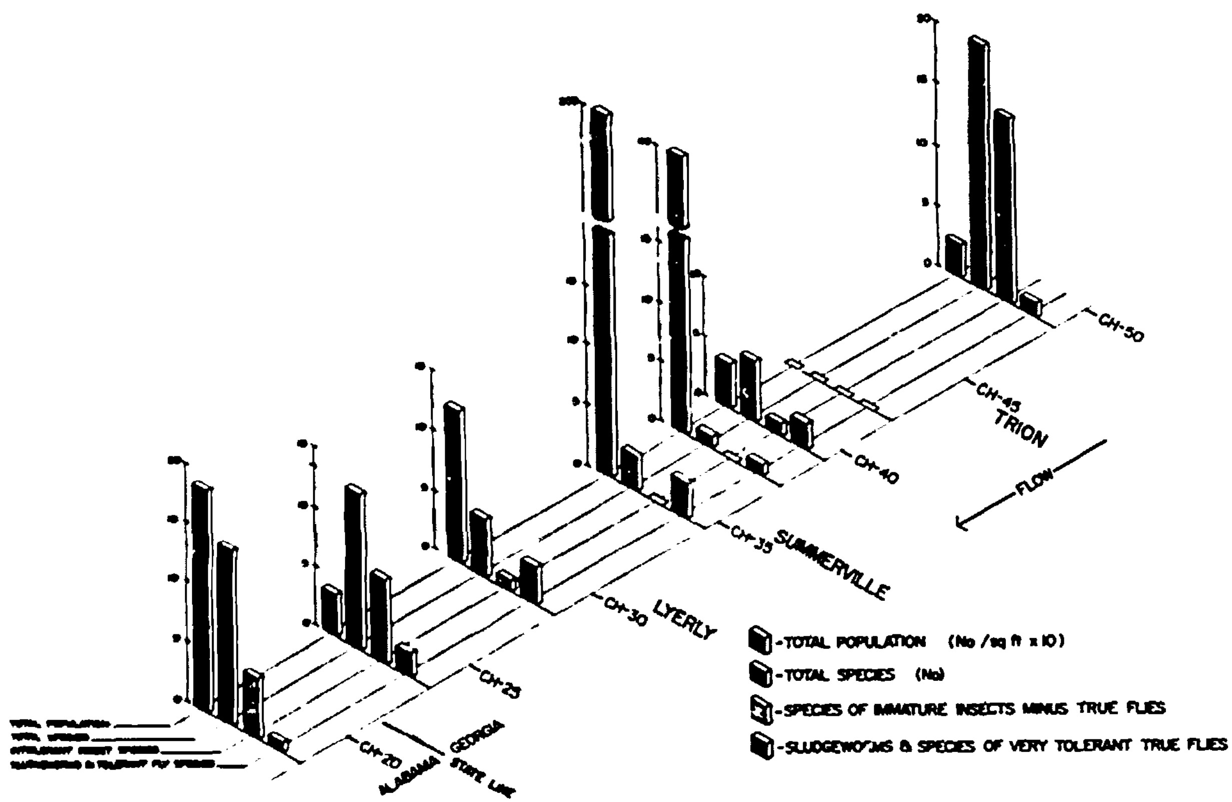

Figure 40. Stream bed animal population in Chattooga River, Ga. August 1962

sensitive insect larvae were drastically reduced or eliminated, and pollution tolerant sludgeworms and associates responded to organic wastes with dense populations where the concentration of toxic materials did not preclude or hamper their existence or development.

Population trends are more easily visualized in figure 40 than in previously discussed three dimensional presentations because the amount of data displayed in one area is less. By means of this device it is possible to form a mental concept among displayed data grouped for a particular station, as well as any single data component among several stations.

Field investigations such as has been described above depict severely toxic conditions. Toxic wastes may eliminate fish populations in certain areas or they may decimate only certain species or certain developmental stages. Adult fish may migrate into an area and live where reproduction is not successful. Some fishfood organisms are more sensitive to certain toxic materials than are fish, and fish populations may be reduced because of a lack of food rather than a direct killing of fish.

Toxic wastes may interfere with the natural purification process in water by interfering with the life processes of those organisms that break down the wastes. The character of the water and its mineral content can alter considerably the toxic effects of a given chemical or waste. The combination of two or more metals may make them several times more toxic to aquatic life than when they occur separately in the environment.

The bioassay is a very important biological tool to use in conjunction with field investigation when toxicities are suspected. The bioassay, conducted under controlled experimental conditions, may be short term (96 hours or less) to determine acute toxicity or long term (days, weeks or months) to determine effects of chronic exposure to test organisms of suspected toxicants, and physiological changes produced within test organisms when exposed to sublethal concentrations of a material that is toxic in higher concentrations. The bioassay may be conducted in a static water environment such as an aquarium, jar, or tank, in a complex flow-through laboratory test chamber, or in situ within the stream or lake. Details for conducting bioassays are presented in the current edition of "Standard Methods for the Examination of Water and Wastewaters."

Mahoning River

In 1952, a steel strike curtailed industrial production along the Mahoning River, Ohio, (Ingram and Bartsch, 1960). July collections were made in that year while the load of remaining pollution came from untreated municipal sewage (Figure 41). September collections were made at the same stations after industrial production was resumed, and the pollutional load consisted of both industrial and municipal wastes. Differences in the number of genera of plants and animals under conditions existing in July and September are shown in the right-hand part of figure 41. Stations 1

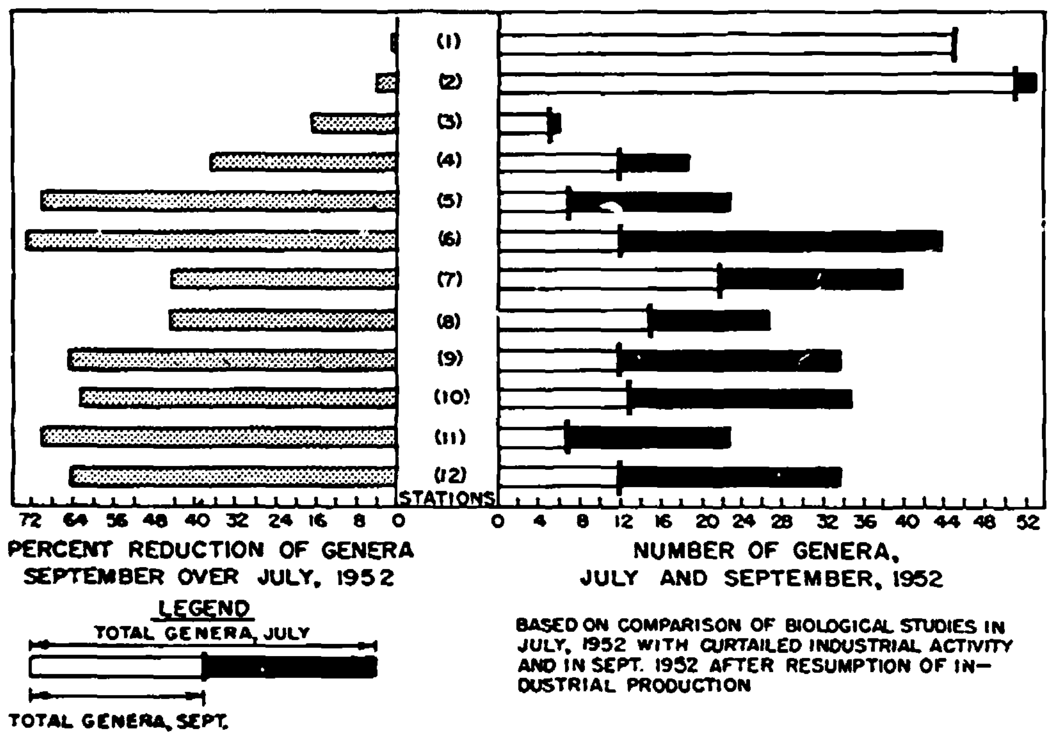

Figure 41. Effects of industrial wastes on genera of organisms in Mahoning River, 1952.

and 2 were control reaches; all other stations were subjected to varying loads of pollution. The left-hand side shows the percentage reduction of genera in September over July, 1952. It is obvious at a glance that the biotic variety of the river was reduced concurrently with resumption of industrial activity and the resulting increased toxic pollutional loads reaching the stream. That the indicated reduction is not attributable to seasonal variation of aquatic life is attested to by the similarities in generic numbers collected at upstream Control Stations 1 and 2 in both July and September.

The Mahoning River drains an area of 1,131 square miles; it begins near Alliance, Ohio, flows northeasterly to Warren, Ohio, southeasterly through Youngstown, Ohio, and joins the Shenango River near New Castle, Pa., to form the Beaver River. One of the most highly industrialized areas in the United States is drained by the Mahoning where 10 percent of this country's steel production is concentrated in its basin.

Maximum river temperatures at Lowellville, Ohio, exceeded 93° F. during 7 months in 1964 in May through November, and exceeded 100° F. in June, July, and September; phenol concentrations were as high as 0.28 mg/l here in January 1965; cyanide values averaged 0.25 mg/l from November, 1952, through September, 1953; ammonia (as NH_3) averaged 3.3 mg/l annually.* Reclaiming operations in the Mahoning River at Youngstown were employed in a 4½-mile reach to separate and remove iron deposits from river bottom sludge.

In a study during the week of January 4, 1965, bottom organisms were reduced in numbers from over 1,300 per square foot upstream from Newton Falls, Ohio, to about 350 per square foot upstream and downstream from Warren, 300 per square foot at Lowellville (Mile 11), and 850 per square foot at the first bridge crossing downstream from the Ohio-Pennsylvania State line (figure 42). Similarly, 11 different kinds of organisms were found upstream from Newton Falls, only one kind, a pollution-tolerant organism, was found at Lowellville (Mile 11), and 3 kinds were found at the first bridge crossing downstream from the State line (figure 43). Although few in numbers downstream from Newton Falls, clean-water associated organisms were found to the highway 422 bridge upstream from Warren, Ohio. Clean-water-associated organisms were not found throughout the remainder of the Mahoning River. Only pollution-tolerant sludgeworms persisted at Lowellville, and only pollution-tolerant sludgeworms and leeches and one kind of tolerant snail were found at the station downstream from the State line. The absence of clean-water-associated fish food organisms in the Mahoning River downstream from Warren, Ohio, the severe decrease in the diversity of bottom organisms, and the generally low numbers of stream bed animals at most sampling

* Report on Quality of Interstate Waters of Mahoning River, Ohio-Pennsylvania. U.S. Department of Health, Education, and Welfare, Public Health Service, Region V, Chicago, Ill., Jan. 1965.

stations, attests to the severely polluted condition of the river and its toxicity from Warren, Ohio, to its confluence with the Shenango River in Pennsylvania.

The bottom of the Mahoning River throughout the reach studied was generally rock and rubble with sludge along the shores and in many slack water areas. Such a rubble substrate would be expected to support a bountiful fish food organism population when not polluted. In many areas, oil formed a film on the water's surface, adhering to twigs, shoreline grasses and debris, and became mixed with the sludges. Substrate

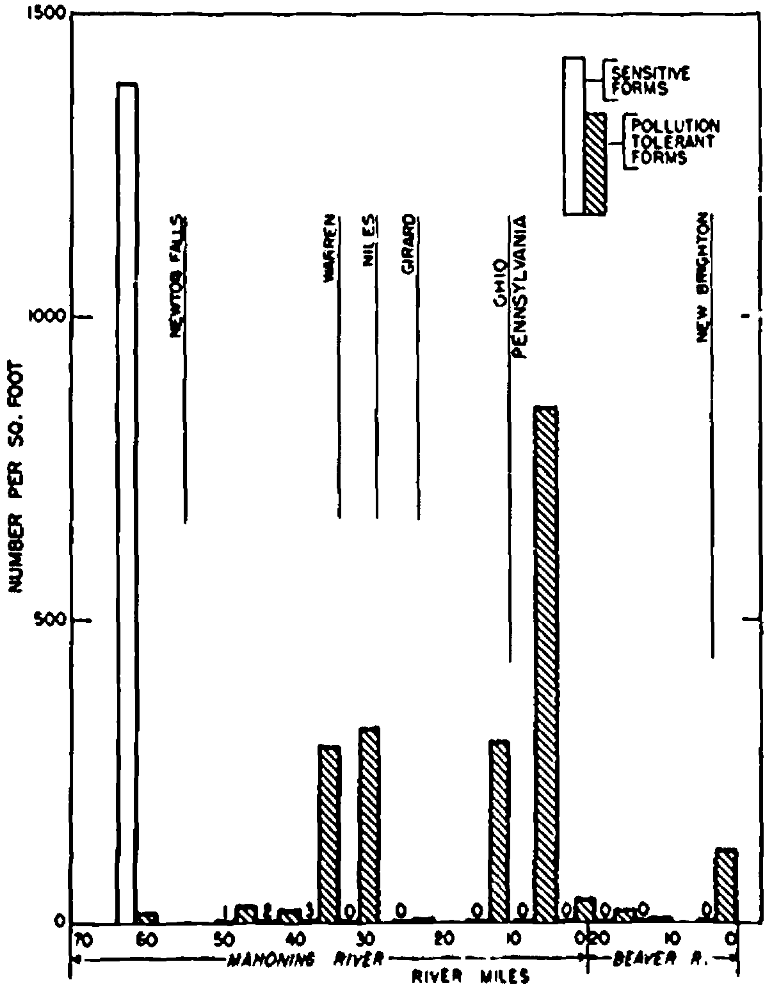

Figure 42. Numbers of stream bed animals, Mahoning-Beaver Rivers, January 1965.

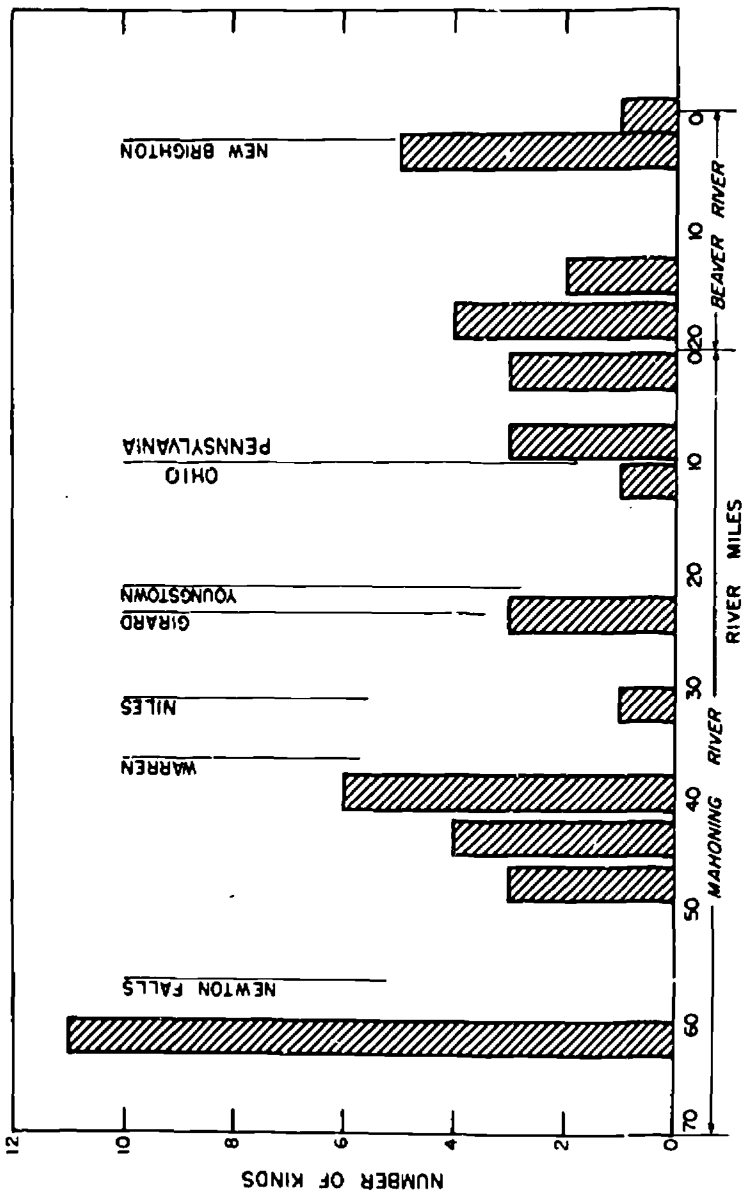

Figure 43. Kinds of stream bed animals, Mahoning-Beaver Rivers, January 1965.

rocks and rubble were covered with a thick iron deposit that was harmful to bottom organisms in the Lowellville-State line reach.

Conditions of existence were only slightly improved in the Beaver

River. Sludgeworm populations were reduced from those found in the more polluted reaches of the Mahoning River, which indicates a reduction in the organic food supply. At New Brighton, Pa., partial stream recovery was found. The different kinds of organisms had increased and stoneflies were observed in small numbers on rocks in the shallow water near the shore. These were not found in quantitative samples taken from deeper water where the impact of pollution would be expected to be greatest.

Oil was also found throughout the Beaver River. Many of the bottom rock were red in color and showed evidence of an iron precipitate. Colonizing the rock's surface in shallower waters was a growth of slick, slimy algae often characteristic of polluted water.

Fisheries investigators have reported that the Mahoning River does not support a catchable fish population downstream from Warren, Ohio, to its confluence with the Shenango River, and that the Beaver River supports a catchable fish population only in its lower reach in the New Brighton area. This was substantiated by an examination of the bottom organism population. In those areas where fishing was not reported, there were no bottom organisms on which fish normally feed.

Results of an examination of the phytoplankton population were similar to those found for the bottom organism population. Values of total counts upstream from Newton Falls, Ohio, were in a range that would be expected in an unpolluted stream during the winter months (figure 44). Downstream from the U.S. Highway 5 bridge (mile 47.4) total count values were substantially reduced and remained so throughout the remainder of the Mahoning River. At Lowellville, Ohio, and at the first bridge crossing downstream from the Ohio-Pennsylvania State line, total count values were one-fourth of those upstream from Newton Falls. Some recovery was found at the highway 18 bridge upstream from the confluence of the Mahoning River with the Shenango River. Depressed algal counts demonstrate the degrading effects of pollution on this primary food source for aquatic life in the stream. The low phytoplankton total count values and the low population numbers found in the bottom organism population is strongly suggestive of the action of a toxic substance or substances to aquatic life.

Ten Mile River

Ten Mile River begins at the outlet of a pond in the northwest part of Plainville, Mass. It follows an irregular course for 21 miles before it joins the Seekonk River in East Providence, R.I. At one time it was stocked with brook trout at Attleboro, Mass., some 8.3 miles downstream from its mouth. During the 1964 survey, it received municipal, plating, pickling, chemical, and textile wastes, and was considered too polluted to be

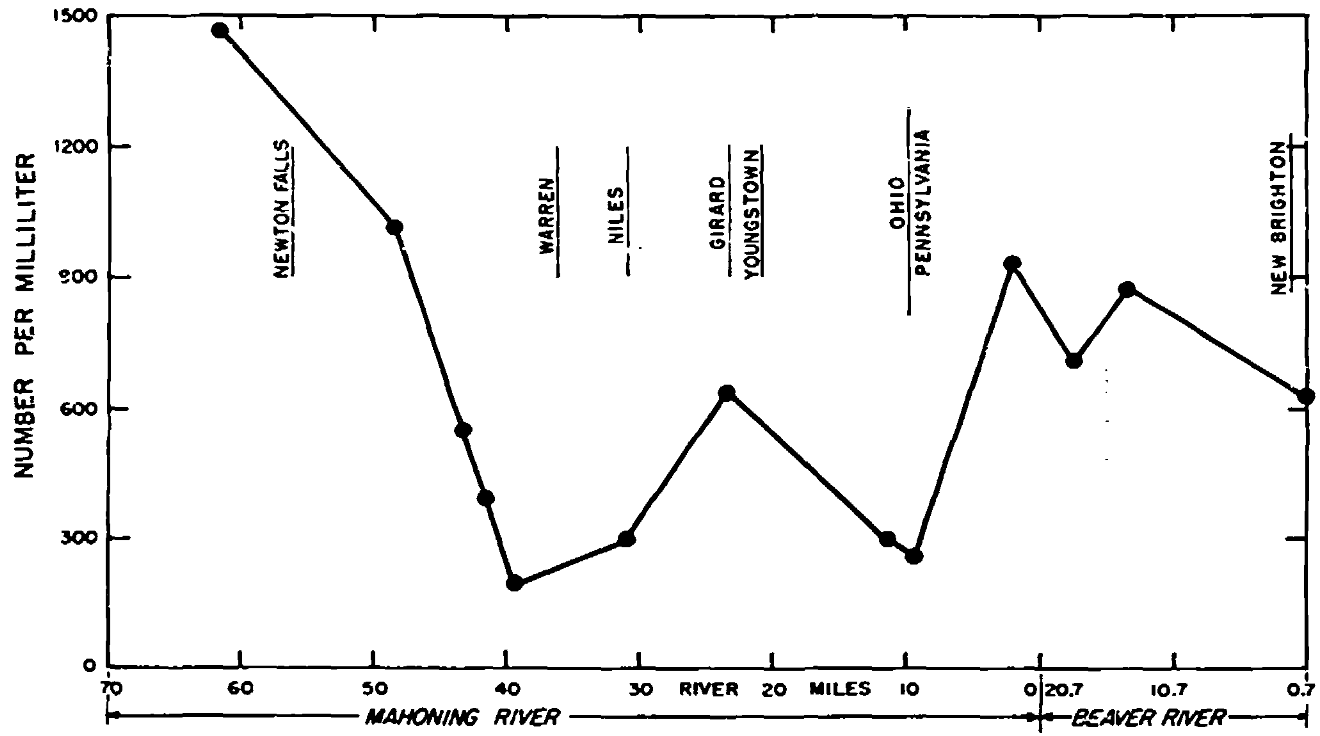

Figure 44. Phytoplankton in Mahoning-Beaver Rivers, January 1965

stocked with any fish downstream from its headwaters.* Thirty-five small metal plating plants are situated in Plainville, North Attleboro, and Attleboro, Mass.

Ten Mile River was severely degraded downstream from North Attleboro, Mass., to the point where it joins the Seekonk River in East Providence, R.I. In this 19 mile reach, Ten Mile River supported a minimal population of clean-water-associated organisms only upstream from North Attleboro.

Extensive sludge deposits, slimes, stalked protozoa, and pollution-tolerant populations of sludgeworms and midges approaching 22,000 organisms per square foot of stream bottom were found in the reach between the North Attleboro sewage treatment plant and Farmers Pond near Attleboro, Mass. (figure 45). Pollution-tolerant sludgeworms and midges were less abundant downstream in Attleboro. Few different kinds of organisms and the presence of extensive sludge deposits impregnated with grease indicated severe pollution and toxicity in this reach of Ten Mile River.

Only 4 kinds of bottom organisms were present in Ten Mile River upstream from the Attleboro sewage treatment plant and the confluence with

* Report on Pollution of Interstate Waters of the Blackstone and Ten Mile Rivers. Op. cit.

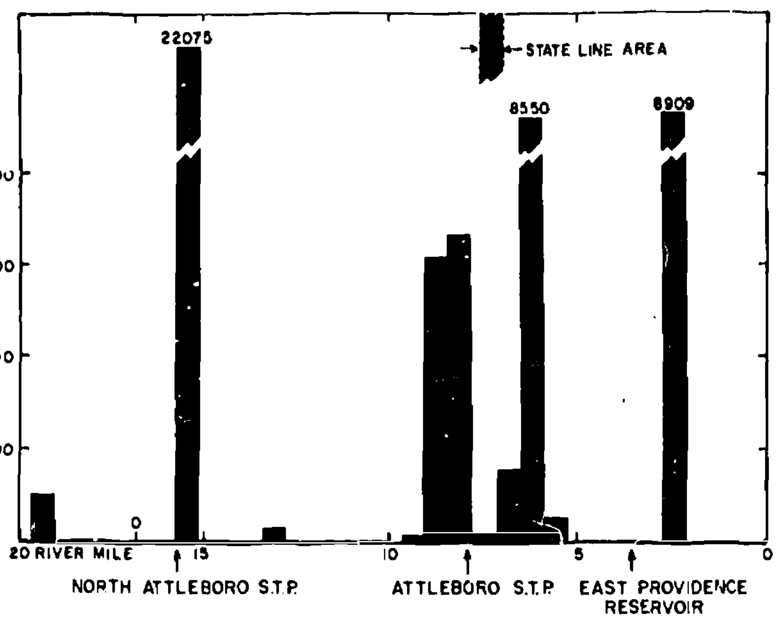

Figure 45. Numbers of pollution-tolerant organisms, per square foot, Ten Mile River, August 1964

an unnamed tributary. Pollution-tolerant midges and sludgeworms were well represented, and stream bottom materials were covered with an oily sludge and slimes. Downstream from this tributary the number of individuals representing the four kinds of bottom organisms was much reduced. Although four kinds of organisms were still present, the decrease in numbers of individuals suggests that wastes entering from the tributary were toxic. No organisms were found in the oily sludge-covered bottom of this purple-black tributary downstream from one of the dyeing and finishing plants.

Effluents from the Attleboro sewage treatment plant contributed to extensive deposition of sludge and, because of unsuitable water quality, a reduction in both numbers and kinds of bottom organisms occurred (Figure 45). Even sludgeworms found conditions of existence restrictive. Slimes, algae, and sludges covered much of the gravel and sandy stream bottom. For the remainder of its length, Ten Mile River exhibited varying degrees of degradation, usually severe.

8

ACID MINE WASTES

A RECENT U.S. Department of the Interior report indicated that 4,800 miles of streams and 29,000 surface acres of impoundments and reservoirs are affected seriously by surface coal mining operations alone (Anon. 1967). Inventories of stream pollution magnitude and source have highlighted the seriousness of the problem. There are about 66,500 sources of coal mine drainage pollution in Appalachia in active and inactive mines. Pollutants in this mine drainage reduce about 10,500 miles of streams below desirable levels of quality* (figure 46).

The pollution of streams by coal mine drainage can be extremely damaging to aquatic life. Streams so polluted generally support only a few species of particularly tolerant plants and animals.

Damages to aquatic life from acid mine drainage are attributed usually to high concentrations of mineral acids, the ions of iron, sulfates, and the deposition of a smothering blanket of precipitated iron salts on the stream bed.** In addition, zinc, copper, and aluminum have occurred at lethal concentrations to aquatic life in acid mine drainage; arsenic and cadmium have been found at near lethal levels. The toxicities are increased by synergism among several of the elements including zinc with copper, zinc with cadmium, and copper with cadmium. Toxicities of iron, copper, and zinc solutions are much greater in acid waters polluted by coal mine drainage than in neutral or alkaline waters. Because of the complex chemical nature of coal mine drainage, it is impossible to assign its toxicity towards aquatic life to any single chemical constituent.

Toxic chemicals in acid mine drainage eliminate sensitive aquatic life; tolerant organisms flourish occasionally to great numbers apparently unaffected by the pollutants. Fish are usually not found when the pH of the

* Stream Pollution by Coal Mine Drainage in Appalachia. U.S. Department of the Interior, Federal Water Pollution Control Administration, 1967.

** Richard W. Warner, Biologist, Technical Advisory and Investigations Branch, personal communication.

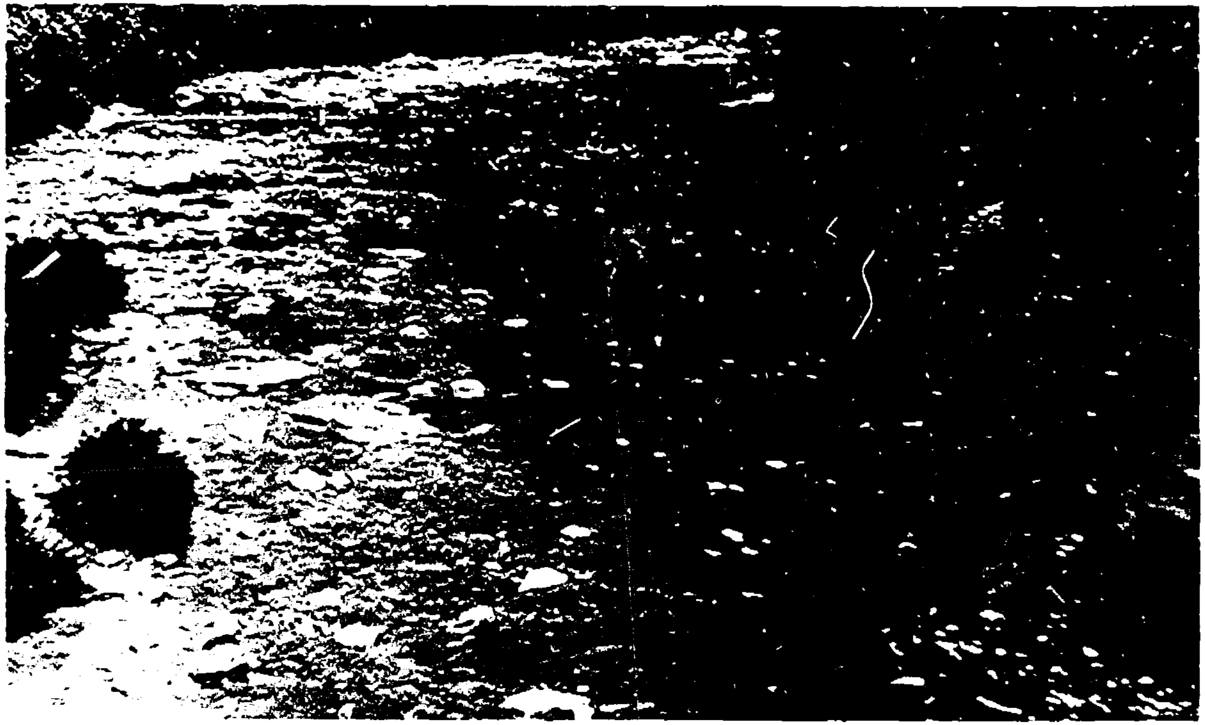

Figure 46. Acid mine discharges kill natural stream bed organisms. Note polluted stream bed on viewers left compared to relatively unpolluted stream bed on viewers right.

stream is lower than 4.5. Conversely, populations of midge larvae, *Chironomus* spp., may develop to nuisance proportions.

With a stream pH of 4.0 or lower, cattails, *Typha* spp., and some mosses will flourish; other vascular plants are not found generally. Moore and Clarkson (1967) studied the Monongahela River, W. Va., and concluded that acid mine drainage does not affect the occurrence and distribution of vascular aquatic plants. They found that nitrogen, calcium, total acidity, iron, pH, and rate of flow had no significant effect on plant distribution, but, that type of substratum was the most important factor affecting plant growth and phosphate content and water level fluctuations were significant.

With a stream pH of 4.0 or lower, dense mats of the green alga, *Ulothrix tenerrima* Kuetzing, are usually common enough to attract the attention of casual observers. Gelatinous mats of chlorophyll-containing flagellates, *Euglena* spp., often color stream beds dark green. Microscopic

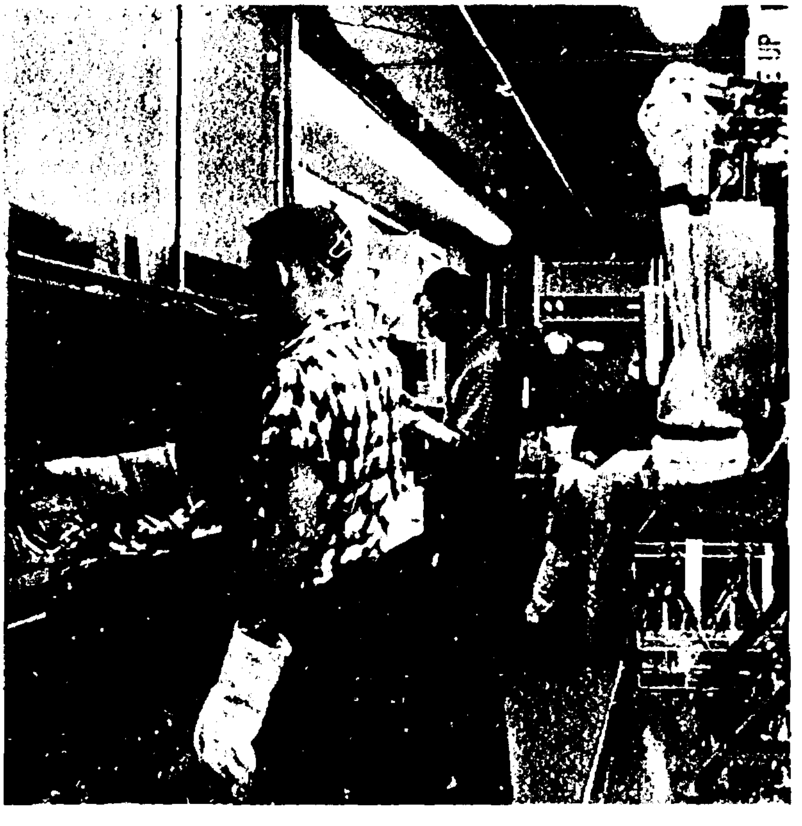

Figure 47. Water quality analyses of stream samples inside a 40-foot mobile laboratory.

examination often reveals other species of green algae including *Microspora* spp., *Microthamnion* sp., the flagellate *Chlamydomonas* spp., great numbers of diatoms *Eunotia* spp., *Pinnularia* spp., and *Navicula* spp., and lesser numbers of *Surirella* spp.

In severely polluted stream reaches, especially near the mine adits from which polluted water flows, no stream bed animals will be found. In less severely polluted reaches, common inhabitants include midges (*Chironomus* spp.), alderflies (*Sialis* sp.), fishflies (*Chauloides* spp.), craneflies (*Antocha* sp.), dytiscid beetles, and caddisflies (*Ptilostomis* sp.). Conspicuous by their absence are crayfish, blackflies, mayflies, stoneflies, and most species of caddisflies.

Upstream reaches, not polluted by acid mine drainage, may support several species of rooted and floating vascular plants, 20 or 30 species of algae, 15 or 20 or more species of stream bed animals, and a mixed community of fishes. Severely polluted stream reaches may support only three or four species of algae. Less severely polluted reaches may support one or two species of vascular plants, three or four species of algae, three or four species of stream bed animals, and no fish.

Dr. Max Katz* summarized much literature on low pH effects and concluded that: pH 6.5 to 7.0 delayed spawning in some fish species but otherwise was harmless except when concentrations of heavy metals or cyanides may be made toxic to fish; pH 6.0 to 6.5 interfered with spawning and hatching of eggs of some fish species; pH 5.0 to 6.0 may be lethal to eggs and larvae of sensitive fish species and will favor dominance of some blue-green algae; pH 4.5 to 5.0 will prohibit reproduction among salmonids and is the threshold range for blackflies, mayflies, and stoneflies in numbers; pH 4.0 to 4.5 permits pike to survive but perch, bream, and roach can only become temporarily acclimated. Observations on pH ranges <4.0 were similar to those described earlier.

Acid pollution of a stream may have additional effects not generally recognized. When water is too acid, it cannot be used for household purposes, livestock watering, or industrial use, without expensive treatment. Wildlife, unwilling to drink acid water, is usually absent near badly polluted areas. Iron hydroxide deposits in stream channels and lack of desirable fish and wildlife in or near acid streams result in decreased land values (Parsons, 1952).

Lackey (1938) writes that one of the most noticeable features of streams or pools receiving drainage from coal mines, either active or abandoned, and their accompanying refuse piles, is the color, varying from almost clear to a deep copper or dark brown. In some instances the water may be clear but appear colored because the stream bed is lined with an iron oxide deposit. Lackey found *Euglena mutabilis* (figure 48) so abundant that they were responsible for a green coating on sticks, leaves, and stones. Such a coating comprised, "at a conservative estimate"

* Dr. Max Katz, University of Washington, personal communication.

Figure 48. *Euglena mutabilis*, showing two or three heavy chloroplastids, conspicuous stigma, small rod-like paramylum bodies, and apparent absence of flagellum. After Lackey (1939).

over 1 million organisms per m.[2] of surface. This one organism, Lackey found, was the most characteristic of highly acid streams. It was present in even the thinnest trickles over vertical faces of rocks in some instances, extending well back into mine openings where there was but little light. The organism is apparently devoid of a flagellum, and its migrations to favored situations must be accomplished by crawling. Lackey found that if a bottle of water containing a large number of the organisms and a half inch of mud were shaken vigorously, the mud settled within 2 or 3 minutes, and in a half hour or less there was a green covering of *Euglena* on its surface. Lackey (1939) listed the number of species of plant and animal groups that occurred below pH 4.0 (table 5).

More than a decade ago, Turner (1958) calculated the monetary damages to 16.3 miles of Goose Creek, a tributary of the South Fork of the Kentucky River, from acid pollution from an operating coal mine to be $13,325. The monetary value was arrived through electro-shocking two similar areas, one upstream from and one downstream from the pollution, and through creel-census.

Table 5. Distribution of Recognized Species of Plants and Animals Occurring at or Below pH 3.9. (After Lackey, 1939)

Plants	Number of Species	Animals	Number of Species
Thallophyta:		Protozoa:	
Fungi	2	Mastigophora:	
Algae:		Euglenidae	7
Myxophyceae	3	Protomastigina	7
Chrysophyceae:		Sarcodina:	
Chrysomonadales	3	Rhizopoda	15
Chrysotrichales	1	Heliozoa	2
Bacillarieae:		Infusoria:	
Pennales	5	Ciliata	19
Chlorophyceae:		Trochelminthes:	
Volvocales	1	Rotatoria	6
Ulotrichales	2	Gastrotricha	1
Chlorococcales	1	Nemathelminthes:	
Zynematales	6	Nematoda	1
Dinophyceae	2	Arthropoda:	
Bryophyta	1	Crustacea:	
Pteridophyta	1	Isopoda	1
Spermatophyta	1	Copepoda	1
		Arachnida:	
		Tardigrada	1
		Insecta	8
		Amphibia	1

Monongahela River System

During August and September 1963, a study was made of the Monongahela River System* Mine drainage, containing sulfuric acid and acid

* Report on Pollution of the Interstate Waters of the Monongahela River System, A. D. Sidio and K. M. Mackenthun, U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, December 1963.

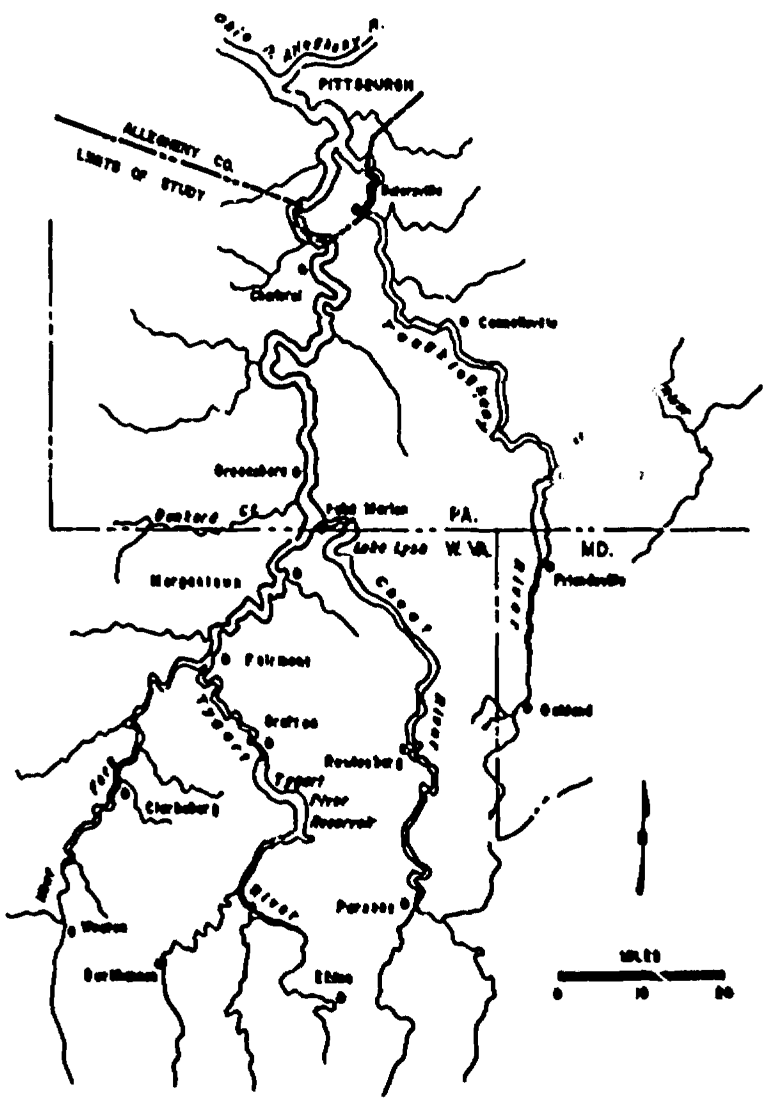

Figure 49. Streams within the Monongahela River Basin.

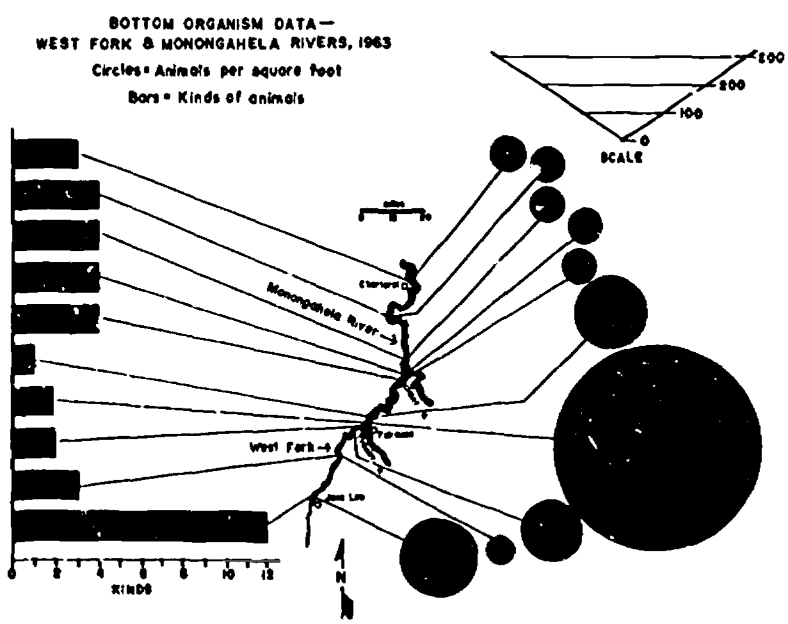

Figure 50. Stream bed organisms, Monongahela River system, 1963.

salts, was the most damaging waste entering the streams within this basin. Annual damages, because of acid conditions in the Monongahela River, were estimated at $2,250,000.

The Monongahela River is formed by the confluence of the West Fork and Tygart rivers at Fairmont, W. Va. (figure 49). The drainage basin includes the southwest corner of Pennsylvania, the northeast portion of West Virginia, and a small section of western Maryland. The basin drains an area of 7,380 square miles. The river flows in a northerly direction and joins the Allegheny River at Pittsburgh, Pa., to form the Ohio River. The main stem of the Monongahela River flows through the Appalachian Plateau region and is characterized by rugged topography, with narrow stream valleys several hundred feet below the level of the uplands.

Downstream from Jane Lew, W. Va., on the West Fork, many different kinds of bottom organisms were collected indicating a healthy stream that is suitable to support fish and other animal life (Figure 50). Aquatic mayfly and caddisfly forms were abundant here. Downstream from this station on both the West Fork and Monongahela Rivers, the stream was degraded by acid mine pollution. The combined effects of acidity and the deposition of sediments caused by mine drainage resulted in a drastic decrease in both kinds and numbers of stream bed animals. At Jane Lew there were 12 different kinds of stream bed animals in collected samples; at all downstream stations there were four or less. At downstream sta-

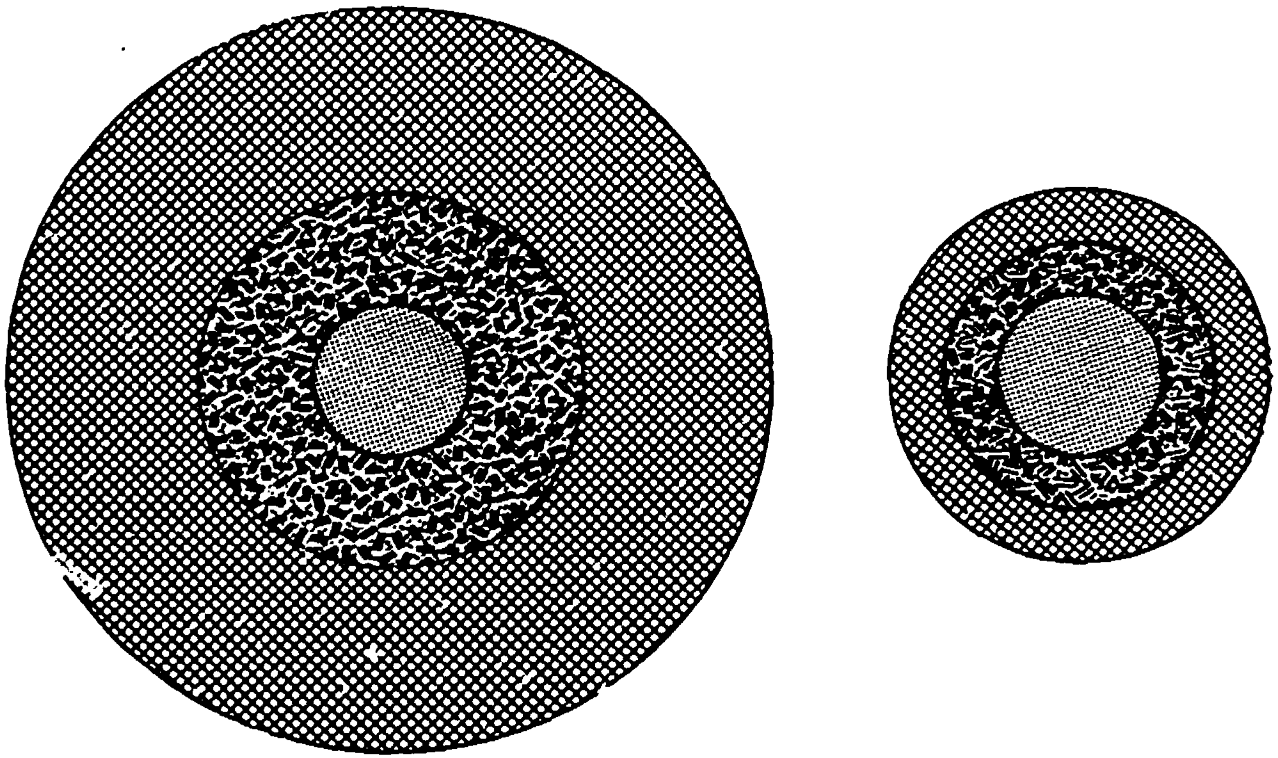

Figure 51. Relative ratios of circle diameters to circle areas. From left and center, 1 : , 2.5 : 2.5, : 5.

tions, the numbers of organisms per square foot were also reduced below the rumbers at the control station, except downstream from Fairmont, W. Va., where sludgewcrms and midges, the only bottom animals present, were found in high numbers because of discharge of sewage and other organic wastes. The pH in the Fairmont area and at all downstream stations ranged from 3.6 to 4.9 during the study. At several stations, coal washing operations made the water black and blanketed the stream bed with coal fines, eliminating living areas for animals. Bottom sediments had an odor of coal and oil.

Figure 50, as a mechanism for data display, leaves room for improvement. Two methods of depicting data are shown on one figure and this tends to create confusion in interpretation. The circles are too close together and the effort would have been enhanced if bars had been used to show both kinds and numbers of organisms.

The numbers of animals per square foot are shown as the diameter of the circle. Often the scale may be omitted on similar figures because the intent is to show relative differences among stations. Some reporters use the diameter of the circle to depict their data while others may use the circle's area. An interesting relationship between circle area and diameter is shown in figure 51. The writer should make his display clear and nondeceptive.

The Cheat River is formed by Shavers Fork and Black Water River upstream from Parsons, W. Va. In Shavers Fork, 13 kinds of stream bed animals including those found only in clean healthy streams were col-

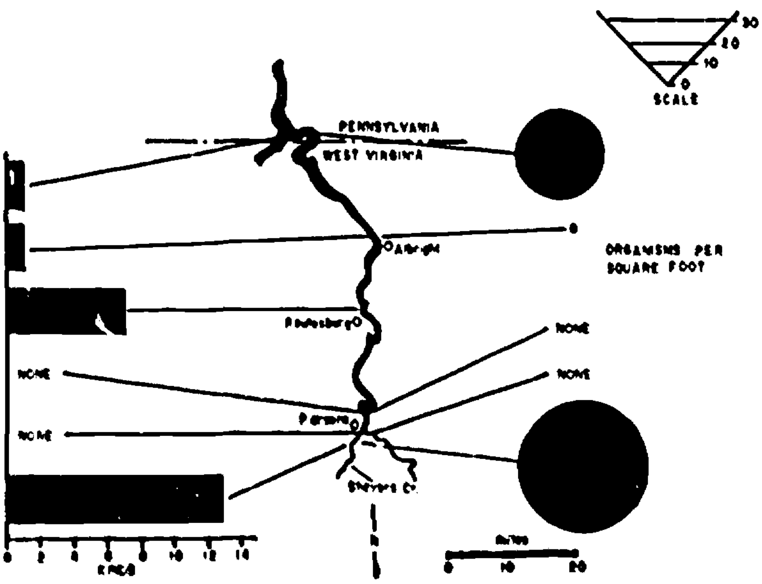

Figure 52. Stream bed animal data, Cheat River, 1963.

lected (figure 52). In Black Water River, stream bed rocks were coated with a reddish deposit characteristic of acid mine drainage and a tolerant alga; they supported no animals.

Downstream from Parsons, W. Va., no stream bed animals were found; those organisms that may have been introduced from Shavers Fork were killed. Some stream recovery was found at Rowlesburg, W. Va., where sampling was limited to a qualitative search because of the sheet rock stream bed. Downstream at Albright, the stream bed habitat was again severely degraded and only an occasional very tolerant organism could be found.

Plankton data confirm the conclusions drawn from a study of stream bed animals. Where conditions of existence were more stringent, and where stream bed animals were reduced in kinds and numbers, planktonic algae were likewise reduced severely in kinds and usually in numbers (figure 53).

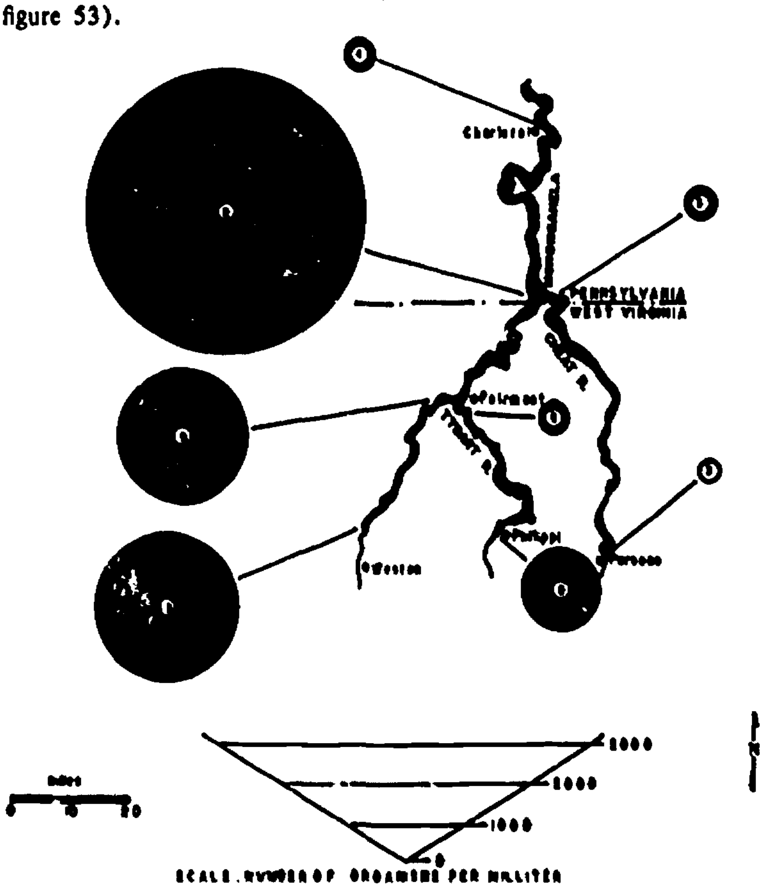

Figure 53. Planktonic algal data, Monongahela River system, 1963.

9

RADIOACTIVE WASTES

KRUMHOLZ (1960) reports that radioactive materials may be accumulated by aquatic organisms in three different ways: (1) By ingestion along with water or food materials; (2) by absorption from the surrounding medium through the body surfaces; and/or (3) by adsorption to the body surfaces. The first two methods are largely biological in nature and the radionuclides enter into the metabolic processes of the organism. The third method is primarily physical in nature and the radio-materials adhere to outer body surfaces. In the latter instance, the size of the organism, because of the tremendous differences in surface-volume ratios of the different ones, is of great importance. In addition, the diversity of structure and surface configuration increase the surface area. Foster and Davis (1955) pointed out that the high radioactivities in plankton and sponges in the Columbia River were associated, in part, with their extensive surface areas.

Radioactive and stable isotopes of the same element have the same chemical behavior, and living organisms are not capable of distinguishing between the two. It is well known that all organisms do not concentrate all chemical elements, but that they select certain elements for their metabolic processes and discard others. Because of this selective power, it is to be expected that they will accumulate any radioactive isotopes of those elements that may be present along with the stable ones.

In an aquarium experiment, Whittaker (1953) showed how biological processes effectively removed phosphorus from the water with algae concentrating the tracer material to levels 300,000 times those in the water. During the first few hours after introduction, the phosphorus was absorbed rapidly by the phytoplankton, but after 15 hours the amounts of radioactivity in the phytoplankton decreased, and more and more of the radiophosphorus was accumulated by the algae on the sides and bottom of the aquatia. Maximum accumulations of radiophosphorus by the algae were reached in 18 days.

Davis, et al (1952, 1953) found concentration factors for radiophosphorus by phytoplankton in the Columbia River to be 100,000 to 200,000 times that of the surrounding water, and Krumholz (1954) reported that the attached freshwater alga (Spirogyra) concentrated radiophosphorus by a factor of 850,000 times that of the water in White Oak Lake.

From the culture of *Escherichia coli* cells in a phosphorus-poor medium containing 25 millicuries (mc) of phosphorus-32, and subsequent release into a small unpolluted stream, the release of the radioactive phosphorus (P^{32}) downstream was investigated (Hooper and Ball, 1966). In moving downstream, approximately 90 percent of the radioactivity remained inside the bacterial cells while 10 percent diffused from the cells and appeared in the water in filterable form. There was a gradual loss of radioactivity from the water because of fallout of labelled cells and uptake by filter-feeding invertebrates. A small amount of the phosphorus-32 released in soluble form by the bacteria was taken up by the periphyton and by aquatic macrophytes. Failure to find important concentrations of radioactivity in any part of the food chain or in the environment suggested that *E. coli* cells effectively dispersed radioactive phosphorus and minimized the transfer activity through segments of the food web leading to man.

There is a general decrease in the level of radioactivity with the decrease in food chain level. Phytoplankton, which absorb nutrients directly from the water, concentrate the largest amounts. Next in order are the herbivorous insect larvae; and then juvenile fish, which feed on bottom organisms. Bass and other game fish, at the end of the food chain, are least radioactive. In a study of smallmouth bass in the Hanford, Washington, vicinity in the Columbia River, fish caught in September had the highest concentration of gross beta activity and fish caught in April the least (Foster and Henderson, 1957). The range in gross beta activity in units of 10^{-6} microcuries per gram of tissue in September fish was 63 to 250 in skin and muscle, 310 to 3,520 in scales and bone, 98 to 840 in internal organs and 700 to 8,240 in stomach contents. Davis (1962) found the insects in the Columbia River within the Hanford Reservation to be many more times radioactive than the waters they inhabit. The most abundant nuclides found in insects were phosphorus-32, copper-64, chromium-51, zinc-65, and sodium-24.

Echo and Hawkins (1966), in studying radionuclides in settling ponds, found that algae not only concentrated the radionuclides in their structure, but that the release of the nuclides might be retarded for considerable lengths of time, especially in waters of low pH. This might form a zone of high activity of undesirable magnitude at the mud-water interface.

Animas River

The Animas River rises in rugged mountains in the vicinity of Silverton

in southwestern Colorado. It flows southerly for 50 miles to Durango, Colorado, and joins the San Juan River about 60 miles south and west of Durango, at Farmington, New Mexico. A uranium mill was located at Durango, approximately mid-way along the river. Upstream from Durango the river is narrow, flowing through mountainous terrain. Where the river flows through Durango it is from 100 to 200 feet wide and has an average depth, during low flow, of about 5 feet. Downstream the river meanders through farmland, then passes through a section of rocky outcrop where its width is restricted to about 150 feet, then again passes through more gentle terrain. Downstream the climate becomes progressively more arid.

The Animas is the domestic water supply for Aztec and Farmington, New Mexico, which had a combined population of 28,000. Downstream from Durango, the Animas provides water to irrigate 26,000 acres of croplands, as well as a recreational area including swimming and fishing.

The uranium refinery at Durango began continuous operation in 1948. Flows in the Animas River at Durango were 250 cfs in 1955 during sampling. Data indicated an approximate discharge of 2.0 milligrams per day of dissolved radium from the Durango refinery. Samples of mud, algae and bottom insects were analyzed in 1955 and again during the 1958 survey (table 6).*

Table 6. Radium 226 in Animas River Samples**

	Water pg/l	Sediment pg/g[1]	Algaa pg/g[1]	Insects pg/g[1]
1955:				
1 mi. upstream from Durango.......	0.2		6	6
2 mi. downstream from Durango....	3.3		660	360
1958:				
1 mi. upstream from Durango.......	0.6	1.7[2]	4.8[2]	4.2[2]
2 mi. downstream from Durango....	12.6	115[2]	390[2]	71

1 dry weight
2 ashed weight

*Survey of Interstate Pollution of the Animas River, Colorado-New Mexico. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Tait Sanitary Engineering Center, Cincinnati, Ohio, May, 1959.

**A picogram (pg) is 10^{-12} gram. In the case of radium, 1 gram very nearly equals 1 curie, where the curie is defined as 3.70×10^{10} disintegrations per second. Thus 1 picogram very nearly equals 1 picocurie or 1 micromicrocurie of radium.

A copper wire screen with 14 wires per inch, one square yard in area, supported at 2 opposite sides by wood strips 1" x 2" x 4 ft. was used to sample bottom fauna in the rocky swiftly flowing stream in 1958. A 1-yd² area immediately upstream from the screen was sampled by wiping the organisms from the rocks and stirring up the bottom. Detached organisms were carried in the current and deposited on the screen. The screen was then lifted from the water and organisms removed with forceps and placed in marked vials.

Mill effluent flowed along one side of the river for some distance before becoming completely mixed with the receiving waters. No stream bed organisms were found on the waste receiving side and organisms were affected adversely in the center of the stream. A population of stream bed animals unaffected by pollution was found on the opposite side.

The scarcity of botton organisms extended for 28 miles downstream from the mill where only 14 insect larvae per square yard were collected in a 7 square yard sample. Forty-three miles downstream from the mill the numbers, kinds and weight of stream bed organisms were nearly equal to the collections upstream from the mill.

Bioassay tests were made to determine the toxicity of the wastes to rainbow trout, the most important game fish in the stream. Several acid waste streams had different toxicities; the most toxic wastes killed 50 percent of the test fish in 96 hours in dilutions containing only 0.09 to 0.21 percent of waste with receiving river water.

A report subsequent to the aforementioned one was dated January, 1960; it described stream studies conducted during the summer of 1959 that were designed to evaluate effects of remedial treatment facilities, principally waste lagooning, installed by the uranium mill during 1959. The mill's discharge of radium between 1958 and 1959 was reduced by 80 percent to 0.059 mg/day. In algae, river mud, and fish there was a definite reduction in dissolved radioactivity in 1959 compared to the earlier year. Just downstream from the pollutional source, river muds contained only 11 percent of the alpha radioactivity in 1959 for an 89 percent improvement over 1958. June high river flows were thought to be responsible for much of the decrease. Algae contained 30 percent of the gross alpha radioactivity value.

The bottom organism population was improved in 1959 in terms of variety of species, but was little improved, compared to 1958, in terms of abundance or weight per square yard of stream bed.

Sigler et al. (1965) have reported on their studies of the Animas River from June, 1960, to July, 1963. The uranium mill at Durango ceased operations in 1963. During 22 sampling trips, water samples contained concentrations of dissolved radium ranging from 0.3 to 2.2 pg/l with background values averaging 0.06 pg/l. In sediments, background radium concentrations were 1.1 pg/g dry weight and samples downstream from Durango ranged up to 27 pg/g in concentration. After May, 1961, sediment values higher than 5.6 pg/g were not found; this reduction was attributed to movement of radium downstream during high spring runoff by leaching, and the transport of radium-bearing biotic components and sediments.

Sigler et al. concluded that the concentration of radium in the water, sediment, algae, and fish of the Animas River decreased from 1958 to 1963. During 1960 to 1963, collections of aquatic organisms indicated that numbers and diversity of the biota downstream from Durango were

similar to those found upstream. Occurrence or abundance of particular organisms varied among stations, but the reasons for such changes were not apparent.

An opportunity arose in 1966 to restudy this portion of the Animas River.* Then, the population of stream bed animals increased from 277 organisms per square yard upstream from Durango to 3,034 organisms per square yard, mostly clean water associated caddisfly larvae, a short distance downstream. Farther downstream, the population was again 230 organisms per square yard. The same sampling device and procedures were used in this survey as in the 1958 and 1959 surveys to make the data reasonably comparable. The sharp population increase downstream from Durango was a response to the organic enrichment in municipal waste discharges from Durango, and the removal of toxic uranium mill wastes. The organic enrichment was insufficient in volume and concentration to eliminate clean water associated organisms, instead, it stimulated the production of some of them.

*A report on biological studies of selected reaches and tributaries of the Colorado River. U.S. Department of the Interior, Technical Advisory and Investigations Branch. Cincinnati, Ohio, prepared in cooperation with the Colorado River Basin Water Quality Control Project, Denver, Colo., 1968.

10

EUTROPHICATION

IT IS well documented that many lakes throughout the country, and the world, have been fertile reservoirs for algal development for many years and have been called eutrophic. Notable for their algal growths in the United States are Lake Zoar in Connecticut, Lake Sebasticook in Maine, the Madison Lakes in Wisconsin, Lake Erie, the Detroit Lakes in Minnesota, Green Lake and Lake Washington in Washington, and Klamath Lake in Oregon.

As nutrient concentrations increase the numbers of algal cells increase. Nuisance conditions occur such as surface scums and algal-littered beaches. The water may become foul smelling. Filter-clogging problems may occur at municipal water treatment installations. Filamentous algae, especially *Cladophora*, grow profusely on any suitable subsurface; these can cause nuisances when they break loose and wash ashore to form windrows of stinking vegetation. The abnormal acceleration of a process that is considered as normal often is not in the best interests of man.

To properly assess a nutrient problem, consideration should be given to all of those sources that may contribute nutrients to the watercourse. These sources could include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and nutrients released from bottom sediments and from decomposing plankton. Transient waterfowl, falling tree leaves, and ground water may contribute important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by these various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantity of nutrient contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are harvested annually through the fish catch, or that may be removed from the system through the emergence of insects, will contribute to an understanding of the nutrient budget.

The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, minimal nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive input attributable to man-made or man-induced pollution that may be corrected as opposed to that input that is natural in origin, and therefore, usually not correctable. A nutrient budget is used to determine the annual input to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments. Examples of nitrogen and phosphorus inputs were presented in tables 2 and 3.

Reservoirs or lakes are the settling basins of drainage areas. The potential productivity of a body of water is determined to a great extent by the natural fertility of the land over which the runoff drains and by the contributions of civilization. Biological activity within the lake influences such chemical characteristics as dissolved oxygen, pH, carbon dioxide, hardness, alkalinity, iron, manganese, phosphorus, and nitrogen; it is varied through temperature fluctuations and stimulated by nutrient variations (e.g., phosphorus and nitrogen). A lake's basin gives dimension to biological activity and may, because of unique physical characteristics, concentrate the nutrients it receives as well as the developing biomass.

The examination of waterway sediments and other solids fits well in a discussion devoted to eutrophication. Sediments are best collected with a device that permits a core of the material to be extracted from which segments may be selected for examination. These identifiable segments may be examined for pollen, diatom skeletons or chitinized remains of cladocerans or midges, as well as selected chemical constituents. Generally carbon and nitrogen, and often phosphorus, are determined. The carbon, nitrogen, phosphorus, and their respective ratios are important values to aid in the identification of a material, to calculate the amount of major nutrients contained within a segment of the biomass or a stratum of sediment, and from which to judge the relative input of nutrients to the water mass when the ecosystem component undergoes decomposition, or natural chemical change (table 7).

Gerloff has been a proponent of a tissue analysis technique to evaluate nitrogen and phosphorus supplies in waters for growth of algae and angiosperm aquatic plants and to determine availability of the elements in lakes from which plants were collected (Gerloff and Krombholz, 1966). They found the critical levels (minimum tissue content associated with maximum growth) to be approximately 1.3 percent nitrogen and 0.13 percent phosphorus for several species of vascular plants. In all but 1 of 9 lakes studied, phosphorus was found more likely to be limiting to higher aquatic plant growth than was nitrogen. In Lake Mendota, Wisconsin, a highly fertile lake, plant samples were collected in June, July, August, and

Table 7. Carbon, Nitrogen, and Phosphorus in Freshwater Environmental Constituents

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Phytoplankton	1,000 to 3,600	100 to 360						Birge and Juday, 1922.
				6.8	0.69		10	Gerloff and Skoog, 1954.
			39	6.1	0.64	6.5	10	Mackenthun et al., 1968.
				9.0	0.52		17	Birge and Juday, 1922.
Attached Algae	2,000	200						Neil, 1958.
				2.8	0.14		2	Birge and Juday, 1922.
Vascular Plants	14,000	1,800						Rickett, 1922, 1924.
				1.8	0.18		10	Harper and Daniel, 1939.
Myriophyllum				3.2	0.52		6	Birge and Juday, 1922.
Vallisneria				1.8	0.23		8	Schuette and Alder, 1928, 1929.
Potamogeton				1.3	0.13		10	Schuette and Alder, 1928, 1929.
Castalia				2.8	0.27		10	Schuette and Alder, 1928, 1929.
Najas				1.9	0.30		6	Schuette and Alder, 1928, 1929.
Myriophyllum				3.0	0.5		6	Anderson et al., 1965.
Bottom Organisms								
Midges	200 to 400	40 to 80						Dineen, 1953; Moyle, 1940.
Chironomus				7.4	0.9		8	Borutsky, 1939.
Hyalella				7.4	1.2		6	Birge and Juday, 1922.
Hirudinea				11.1	0.8		14	Birge and Juday, 1922.
Sialis				8.1	0.6		14	Birge and Juday, 1922.

Fish	150 to 600						Swingle, 1950.
			[2]2.5	[2]0.2		10	Beard, 1926.
			2.8	0.18 to 0.49			Borgstrom, 1961.
				0.19			Love et al., 1959.
				0.20			McGauhey et al., 1963.
				0.29			Sylvester and Anderson, 1964.
Domestic Wastes[3]			2.6 to 3.3	0.18 to 0.24			Ingalls et al., 1950.
				5.1 to [4]10.6			Engelbrecht and Morgan, 1959.
			[4]45	[4]8		6	McGauhey et al., 1963.
			20 to [4]40	5.3 to [4]10.6		4	Bush and Mulford, 1954.
			[4]61.3	[4]10.7		6	Oswald, 1960.
			18 to [4]28	3.5 to [4]9.0			Anon, 1967.
Sediments							
Lake Tahoe		0.6 to 19.8	0.6 to 1.6		4 to 25		McGauhey et al., 1963.
Wisconsin Lakes		4.4 to 40.5	0.6 to 3.6	0.12 to 0.6	8 to 14	5 to 6	Black, 1929; Juday et al., 1941.
Madison, Wis. Lakes			0.7 to 0.9	0.1 to 0.12		6 to 9	Sawyer et al., 1945.
Green Lake			0.6	0.17		4	Sylvester and Anderson, 1964.
Lake Sebasticook		10 to 34	0.3 to 1.8	.06 to .16	8 to 44	5 to 16	Mackenthun et al., 1968.
Klamath Lake		8.6	1.2		7		Thomas, N. A., Unpublished.[5]
Boston Harbor		2.3 to 5.0	.06 to .41				Stewart, R. K., 1968.[5]
Organic River Sediments		0.03	0.0027		12		Finger and Wastler, 1969.

[1] As the total element in percentage of the dry weight, unless specified otherwise

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Pulp & Paper Wastes in River			5.3	0.23		22		Finger and Wastler, 1969.
Untreated Domestic Wastes			3.54	0.3		12		Finger and Wastler, 1969.
Untreated Chemical and fertilizers and domestic wastes			3.15	0.12		26		Finger and Wastler, 1969.
No tributary wastes			0.55	0.05		11		Finger and Wastler, 1969.
Sand; silt; clay; loam			0.4 to 2.1	.02 to .10		20		Ballinger and McKee, Unpublished.[6]
Stable sludge; peat; organic debris			2.0 to 5.0	.10 to .20		20 to 25		Ballinger and McKee, Unpublished.[6]
Paper mill wastes			6 to 15	.10 to .30		50 to 60		Ballinger and McKee, Unpublished.[6]
Packinghouse Wastes			2.8 to 4.3	.30 to .50		8 to 10		Ballinger and McKee, Unpublished.[6]

Fresh sludge; decaying algae; sewage solids	5 to 40	.70 to 5.0		7 to 8		Ballinger and McKee, Unpublished.[6]
Log Pond Bark	50.6	.5	.02	100	25	Thomas, N. A. Unpublished.[6]
Sewage sludge in river	5.8	0.23	.18	21	2	Thomas, N. A. Unpublished.[6]
Algae; sawdust; sewage	14.6	0.93	.11	16	9	Thomas, N. A. Unpublished.[6]
Leaf litter	28.3	1.63	0.11	17	15	Warner, R. W. et al., 1969.[7]
Sand	0.2	.02	.005	10	4	Warner, R. W. et al., 1969.[7]
Loam	2.7	.19	.02	14	10	Warner, R. W. et al., 1969.[7]
Muck	7.3	.52	.04	14	13	Warner, R. W. et al., 1969.[7]
Floating Waste Wool	37 to 43	3.4 to 4.7	.08 to .09	9 to 11	38 to 58	[8].

1 As the total element in percentage of the dry weight, unless specified otherwise.
2 Calculated on wet weight.
3 Average sewage flow can be calculated at 100 gallons per capita per day.
4 mg/1
5 Biological Aspects of Water Quality, Charles River and Boston Harbor, Massachusetts by R. K. Stewart. Technical Advisory and Investigations Branch, Cincinnati, Ohio (1968).
6 Technical Advisory and Investigations Branch, Cincinnati, Ohio.
7 Analyses of soil types from "Black-Water Impoundment Investigations," by R. W. Warner, R. K. Ballentine and L. E. Keup, Technical Advisory and Investigations Branch, U.S. Department of the Interior, Cincinnati, Ohio (1969).
8 Fertilization and Algae in Lake Sebasticook, Maine. Department of Health, Education, and Welfare, Technical Advisory and Investigations Activities, Cincinnati, Ohio (1966).

September. The percentage of nitrogen in plant tissues of *Ceratophyllum demersum* varied from 2.11 to 4.43 among these monthly samples while percentage phosphorus varied between 0.51 and 0.75. Among 6 plant species, the percentage of nitrogen varied from 1.98 to 4.43 and phosphorus from 0.23 to 0.75. In Lake Nebish, Wis., a relatively infertile lake, the variance among 4 plant species among the same months was 1.48 to 3.19 percent nitrogen and 0.10 to 0.33 percent phosphorus.

The carbon-nitrogen and nitrogen-phosphorus ratios are of greater value in data interpretation than are total to soluble phosphorus ratios. Total to soluble phosphorus ratios may vary from 2 to 17 or even 90 percent dependent upon the particular water, season, aquatic plant populations, and probably other factors (Table 8). These ratios are of value when they can be determined periodically within the same water body and changes in them correlated with volumetric response changes within the algal mass.

Table 8. Total to Soluble Phosphorus Ratios in Water

Water	Total P:Sol.P	Reference
Western Lake Erie	3.5	Chandler and Weeks, 1945.
Detroit River mouth	5 to 7	PHS Detroit Project.
Linsley Pond, Conn.	10.0	Hutchinson, 1957.
Northern Wisconsin Lakes	7.0	Juday and Birge, 1931.
Northeast Wisconsin Lakes	2 to 10	Juday et al., 1927.
Ontario Lakes (8)	17	Rigler, 1964.
Southeast Wisconsin Lakes (17)	9	Mackenthun, unpublished.
Rock River, Wis.	2 to 15	Mackenthun, unpublished.
Sebasticook Lake, Maine	2.8 winter	Mackenthun et al. 1968.
Do	12.7 spring	Do.
Do	7.0 summer	Do.
Do	4.1 fall	Do.

The nutrient loading to the lake on a unit basis gives some measure of comparability among various water bodies (table 9). Likewise, a lake or reservoir usually retains a portion of those nutrients that it receives from its various sources. The amount or percentage of the nutrients that may be retained by a lake or reservoir is variable and will depend upon:

1. the nutrient loading to the lake or reservoir;
2. the volume of the euphotic zone;
3. the extent of biological activity;
4. the detention time within the basin or time allotted for biological activity; and
5. the level of the penstock or discharge from the basin.

Lake Sebasticook, Maine

Lake Sebasticook at Newport, Maine,* was plagued with nuisance algal growths caused principally by nutrients contained in domestic and in-

* Fertilization and Algae in Lake Sebasticook, Maine. Technical Advisory and Investigations Activities, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1966.

Table 9. Lake Nutrient Loadings and Retentions

Lake	State	Nitrogen (N)		Phosphorus (P)		Reference
		Loading lb./yr./acre	Retention (Percent)	Loading lb./yr./acre	Retention (Percent)	
Washington	Wash.	280	...	12	...	Anderson, 1961.
Mendota	Wis.	[1]20	...	[2]0.6	...	Anon., 1949.
Monona	Wis.	[1]81	48 to 70	[2]7.5	64 to 88	Lackey and Sawyer, 1945.
Waubesa	Wis.	[1]435	50 to 64	[2]62.8	−26 to 25	Do.
Kegonsa	Wis.	[1]162	44 to 61	[2]35.9	−21 to 12	Do.
Tahoe	Calif.	2	89	0.4	93	Ludwig et al., 1964.
Koshkonong	Wis.	90	80	40	30 to 70	Mackenthun, unpubl.
Green	Wash.	...	...	4.8	55	Sylvester and Anderson, 1964.
Geist	Ind.	[1]440	44	28	25	F.W.P.C.A. Data.
Sebasticook	Maine	...	...	2	48	Do.
Ross R. Barnett	Miss.	...	...	32	...	Do.

[1]Inorganic nitrogen only. [2]Soluble phosphorus only.

dustrial plant wastes that were discharged to the East Branch of the Sebasticook River at Dexter and Corinna, Maine. Along with other nutrients, the Lake received annually about 8,000 pounds of total phosphorus, 75 percent of which was contributed by domestic and industrial wastes. These nutrients produced as much as 9.7 million pounds of algae as a standing crop within the lake during those days of the year that were optimal for algal development. Algae were swept by winds and waves into bays and coves where they decomposed in the hot sun forming a "green-paint" covering on rocks, boats, and piers, releasing a pungent pig-pen odor in decay.

The field study, made in 1965, encompassed the East Branch of the Sebasticook River from Lake Wassokeag to the inlet of Lake Sebasticook (a distance of 10.5 stream miles); Alder Stream, tributary to the East Branch; Stetson and Mulligan streams, tributary to Lake Sebasticook (fig. 54); Lake Sebasticook (fig. 55); and the lake's outlet. The purpose of the study was: (1) to identify major sources of nutrients to Sebasticook Lake; (2) to assess their significance; and (3) to recommend the most feasible nutrient control measures that will effect a lasting reduction in the aquatic growths. Field studies were conducted during the winter ice-cover in early February, just following the spring lake turn-over from May 11 through 18, the summer maxima of aquatic vegetation growth from July 26 to August 2, and the fall lake turn-over during the last week of October and the first week of November.

Samples for analyses for nitrogen (organic-N, NH_3-N, NO_3-N) and for total and dissolved phosphorus were fixed with 1 ml H_2SO_4 per liter and shipped to Cincinnati, Ohio, in polyethelene containers. Samples for dissolved phosphorus analysis were filtered shortly after collection and shipped separately. Analytical procedures were according to Standard Methods for the Examination of Water and Wastewater (Twelfth Ed.).

Field collections of water for plankton analyses were preserved with 4 percent formalin and shipped to the Cincinnati laboratory. Phytoplankton counts were made using the Sedgwick-Rafter counting cell following Standard Methods for the Examination of Water and Wastewater. Microscopic measurements were made of a selected number of predominant organisms and the wet algal volume was determined by the following formula:

Algal volume (p.p.m.) = Number of organisms per millileter $\times$ average species volume in cubic microns $\times 10^{-6}$.

Chlorophyll bearing cells were filtered from the water with membrane filters (0.45 micron pore). Filters and cells were placed in vials of acetone for extraction of the pigments and for solution of the filters (Creitz and Richards, 1955). Samples were then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone was examined on a recording spectrophotometer. Spectrums were eval-

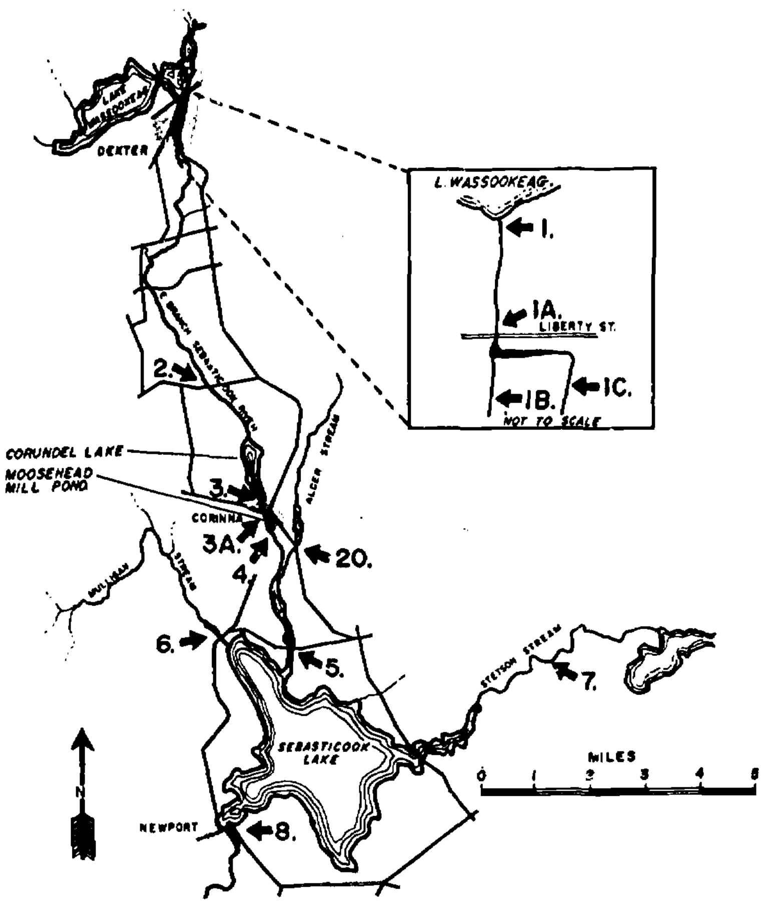

Figure 54. Sampling station locations on tributary streams, Lake Sebasticook, Maine.

uated and the quantity of cholorophyll determined as outlined by Richards with Thompson (1952).

An aliquot solids sample based on a packed volume of a selected core segment was oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) were added, the mixture cooled, washed into a centrifuge tube, and water added. The sample was washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue was then diluted to a specific volume of water (200 ml per gram of original sample), 2 drops of liquid household detergent were added, the sample stirred, and 2 drops of sample were withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover

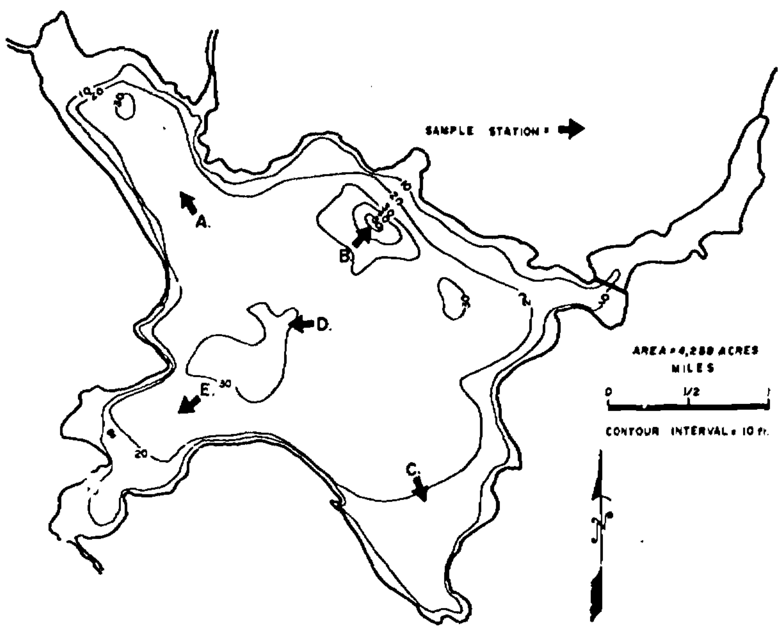

Figure 55. Sampling station locations on Lake Sebasticook, Maine.

slip was evaporated to dryness on a hot plate. Following dryness the hot plate temperature was increased to 350° F., a clean microscopic slide was placed thereon, and a large drop of Hyrax mounting media was placed on the slide. After 10 minutes, and slight cooling, the cover slip with dried sample was inverted onto the Hyrax drop and pressed firmly into place. The slide was then examined for diatom skeletons.

The Sebasticook Lake drainage basin has an area of 126 square miles. The lake is fed by runoff from three main tributary streams: Mulligan Stream having a drainage area of 20.9 square miles, the East Branch of the Sebasticook River, with a drainage area of 56.2 square miles, and Stetson Stream, with a drainage area of 28.6 square miles. About 8,600 people resided in the area.

Mulligan and Stetson streams drained rural areas which were sparsely populated. There were no known significant nutrient waste discharges to these streams. The East Branch of the Sebasticook River received discharges of municipal and industrial wastes from the urban portions of the Towns of Dexter and Corinna. The river received wastes from 2 woolen mills in Dexter that produced woolen yard goods from raw stock, which had been scoured prior to receipt. Wastes consisted of batch dumps of spent washing and dyeing solutions and large volumes of rinse waters. Another woolen mill discharged wastes downstream at Corinna, Maine. Also near Corinna, a potato canning company discharged phosphorus-rich

wastes from the processing of 170 to 190 tons of potatoes daily during 9 to 10 months of the year.

The East Branch of Sebasticook River from Corinna, Maine, to the inlet of Lake Sebasticook was severely polluted. Dye wastes colored the water purple, and luxuriant growth of aquatic slimes, wool fiber mats, potato sprouts, and rotting potatoes were visible in certain areas. Downstream, this reach divides naturally into three ponded areas totaling 167 acres that serve as waste stabilization sites. Floating masses of wool dotted the surface of these waters and rising gas bubbles from decomposition pockmarked the stream reach. The discharge from the downstream waste stabilization site is the principal inlet to Lake Sebasticook.

Results of 1,400 nitrogen and phosphorus analyses showed that total nitrogen added to Sebasticook Lake by the East Branch of the Sebasticook River ranged from 445 to 778 lb./day during the 4 survey periods, and total phosphorus ranged from 15 to 30 lb./day during the February, May, and October surveys. Only 9.3 lb./day of total phosphorus were added during the July survey, when the potato-canning company was not in operation. In the Corinna area, about 85 percent of the nitrogen contributions came from the woolen mill, and 55 percent of the phosphorus discharged to the stream was from the canning company. Of all nitrogen and phosphorus sources to Lake Sebasticook, the East Branch of the Sebasticook River was the principal contributor because of discharges of municipal and industrial wastes (Mackenthun et al., 1968).

Within one-half mile of Sebasticook Lake, 16,700 lb./yr of phosphorus were contained in the fertilizers applied to 230 acres of agricultural lands that grow potatoes, apples, alfalfa, beans, and corn. Some of these nutrients, perhaps 100 lb./yr, reached the lake and contributed to the algal problem. This was approximately 0.6 percent of the phosphorus applied to the agricultural soils and less than 2 percent of the annual total phosphorus entering Lake Sebasticook.

Waste disposal facilities for 269 shoreline dwellings included 190 septic tanks and 79 privies. Assuming 4 persons per dwelling with an average occupancy of 3 months, the population equivalent on an annual basis was 269 and the contribution of total phosphorus was 800 lb. Many private wastewater disposal units either were located or discharged only 20 ft or less from the waters of Lake Sebasticook and thus contributed between 5 and 10 percent of the total phosphorus load to the lake.

The soil and subsoil as well as the underlying strata through which underground water passes are natural sources of lacustrine phosphorus. Eight shallow wells and one spring located on the shores of Sebasticook Lake were analyzed for nitrate-nitrogen and total phosphorus. With the exception of a 38-ft artesian well with 3.45 mg/l, the NO_3-N in these well samples did not exceed 0.04 mg/l. The total phosphorus in one well was 0.07 mg/l, in an 18-ft deep well and a 2-ft deep spring it was 0.02 mg/l, and in the remaining wells was 0.01 mg/l or less.

Lake Sebasticook lies in a forest transition zone between the spruce-fir and northern hardwoods forests. Tamarack, eastern hemlock, white pine, spruce, balsam fir, maples, beech, black ash, and quaking aspen abound. The amount of nitrogen from pollen may be as high as 2 to 5 pounds per acre per year in a forested area (McGauhey et al., 1963). Pollen contains phosphate in addition to nitrogen, but pollen is known to remain essentially intact in the sediments and it cannot be assumed that these materials are released to the lake water. Likewise, about 20 pounds of nitrogen and 2 pounds of phosphorus per acre are returned annually to the soil by forest tree leaves (Donahue, 1961). The amounts of these materials reaching Lake Sebasticook would depend upon the leaching of soluble materials to the lake from adjacent leaf litter and that direct contribution arising from wind-blown leaves. This amount would be expected to be small in comparison to the total nutrient loading to the lake.

Vertical water temperatures and dissolved oxygen concentrations were taken during the May, July, and November studies from the deepest portion of the lake (fig. 56). The May study was conducted just following the spring overturn, and the November study was conducted during the fall overturn when the entire water volume of the lake was being mixed by winds. Dissolved oxygen was present from surface to bottom and especially during November the temperature did not vary from surface to bottom.

During the latter part of July, Lake Sebasticook was stratified. The thermocline began at a depth of 32 feet and extended downward to 44 feet. The dissolved oxygen was less than 1 mg/l at the beginning of the thermocline and was zero at a depth of 35 feet. The dissolved oxygen curves for the afternoon of July 29 and the morning of July 30 have a different profile in the upper waters and reflected the effects of the large mass of algae that was present at this time.

Analyses for organic N, NH_3-N, NO_3-N, total P, and soluble P were made on 820 water samples collected vertically at 10-ft intervals from 5 stations within the lake (fig. 55). During February, maximum ammonia nitrogen and organic nitrogen concentrations combined to make total nitrogen values of 3.3 mg/l in the surface waters and 6.2 mg/l in the profundal waters. Total phosphorus was stratified with depth; it was 0.05 mg/l in the surface waters and 0.37 mg/l in the profundal waters. Soluble phosphorus was 0.011 mg/l in the surface waters. During spring and summer, the total nitrogen decreased to about half of the February values; however, the inorganic nitrogen exceeded 0.3 mg/l at all depths and was greater than 0.45 mg/ in the surface waters. Total phosphorus was 0.05 mg/l in the surface waters in May and 0.06 to 0.07 mg/l in summer. Soluble phosphorus concentrations were 0.004 in autumn. Considering the four seasons, there was no reduction in nitrogen passing through the lake.

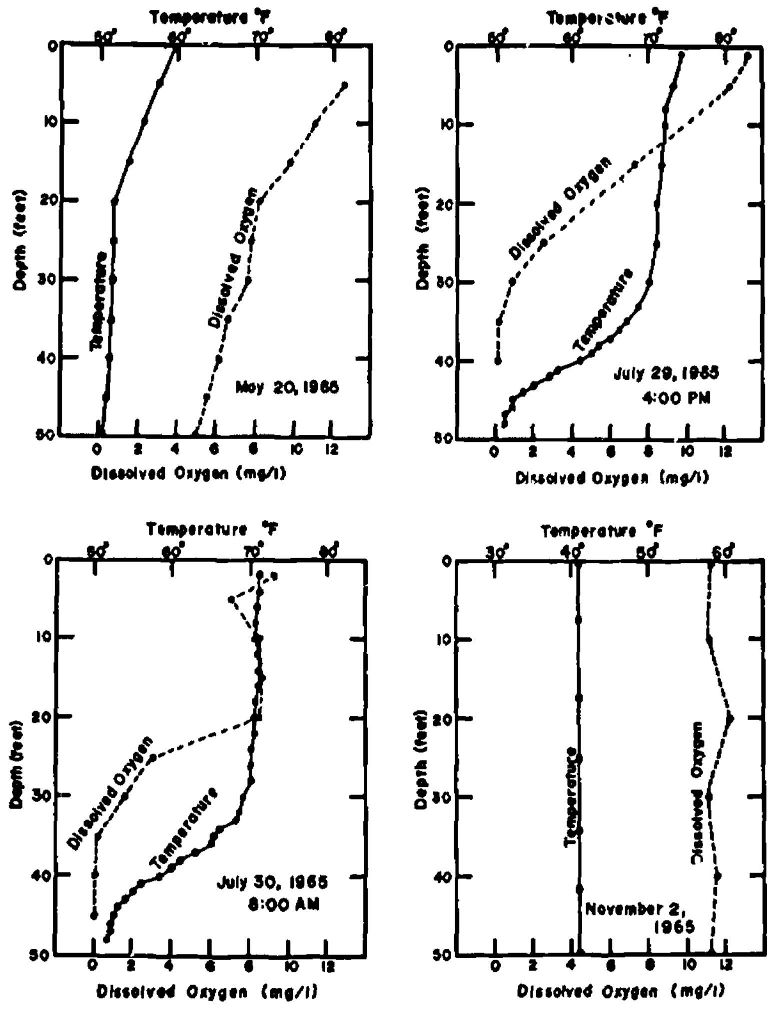

Figure 56. Vertical temperature and dissolved oxygen curves, Lake Sebasticook, Maine

Total phosphorus in the lake was most abundant during the summer (table 10). During the autumn and winter seasons the phosphorus was at the annual minimum. The ratio of total to soluble phosphorus was 2.8 in February, 12.7 in May, 7.0 in August, and 4.1 in November; this variation may be attributed to changes in amounts of algal growth during the different seasons. If the 4 sampling periods are representative of the 4 seasons of the year, the lake received 8,000 lb of total phosphorus annually; it dischargd 4,150 lb and retained 48 percent of the phosphorus. The period of water detention in the lake was calculated to average 3.5 yr.

Table 10. Nutrient and Algal Quantities in Lake Sebasticook, Maine, 1965

Pounds	February	May	August	November
Algae (wet) (x10^6)	2.29	2.70	4.4–9.7	2.46
Total P (x10^3)	9.2	11.4	14.8	9.1
Soluble P (x10^3)	3.3	0.9	2.1	<2.2
Organic N (x10^3)	390	222	197	197
Inorganic N (x10^3)	321	109	89	25

Phytoplankton counts in the surface waters of the lake ranged from 600/ml in February to 212,000/ml during a bloom on August 1. The volume of the algal mass varied between 15 and 19 p.p.m. in the surface waters except during the summer study, when 48 p.p.m. and 560 p.p.m. were recorded. The wet weight of phytoplankton per surface area was calculated to be 530 lb./acre in February, 630 in May, 1,000–2,260 in August, and 570 in November.

In the stabilization area, just upstream from the lake inlet, the quantity of chlorophyll *a* increased gradually toward the inlet of Lake Sebasticook (fig. 57). The grossly polluted water entering this area supported very few algae. As this water became less polluted through the setting of suspended solids and the decomposition and stabilization of organic materials, algae increased in numbers as nutrients became available from decomposing wastes.

A 19-inch sediment core was collected from a depth of 53 feet in Lake Sebasticook. Segments of the core were oven dried and analyzed for the percentage of carbon, nitrogen and phosphorus (table 11).

The dry weight phosphorus (P) in the 0–1 inch stratum was 0.15 percent. Assuming the lake bed sediments contain 15 percent solids, the upper 1-inch stratum of Lake Sebasticook just beneath the mud-water interface might then contain about 200,000 pounds of phosphorus. The 1–2 inch stratum contained 0.09 percent phosphorus or about 120,000 pounds for the entire lake—some 80,000 pounds less phosphorus than the inch immediately above it. The 2–3 inch stratum contained 0.06 percent or about 80,000 pounds of phosphorus. Beneath the 1–2 inch stratum the phosphorus content ranged from 0.06 to 0.09 percent on a dry weight basis.

Several 1-inch segments of the core were examined microscopically to enumerate diatom fragments and complete skeletons (table 12). Diatom shells or skeletons are composed of siliceous minerals that resist decomposition. Beginning at the mud-water interface with the most recent deposition and proceeding downward within the sediments, two periods occurred within the examined history of the lake when the diatom population increased at a rapid rate. This phenomenon would be expected during periods of accelerating enrichment. These periods occurred during the time between deposition of the 1–2 and 4–5-inch strata, and earlier between deposition of the 7–8 and 11–12-inch strata. The periods appear

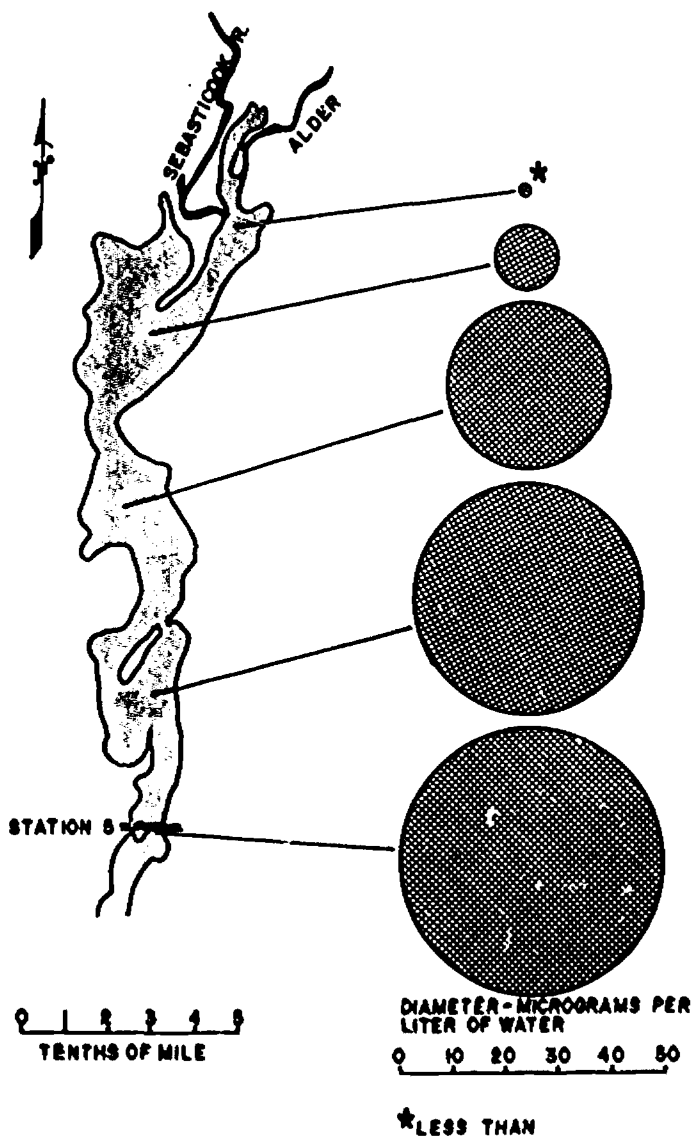

Figure 57. Chlorophyll entering Lake Sebasticook, July 29, 1965.

to be separated by years when the diatom production was less phenomenal.

The kinds of diatoms found are also indicative since different species attain abundance in different types of water. Those kinds predominating in the upper Lake Sebasticook sediments were: *Stephanodiscus astraea*

Table 11. Organic Carbon, Nitrogen, and Phosphorus in Sediments Lake Sebasticook, 1965

Lake sediment core	Carbon (Percent dry weight)	Nitrogen (Percent dry weight)	Phosphorus (Percent dry weight)	C:N	N:P
Inches:					
0-1	11.0	0.6	0.15	18	4.0
1-2	6.5	0.5	0.09	13	5.6
2-3	4.0	0.4	0.06	10	6.7
3-4	3.0	0.5	0.06	6	8.3
4-5	4.0	0.3	0.06	13	5.0
5-6	3.7	0.3	0.06	12	5.0
6-7	3.2	0.3	0.09	11	3.3
7-8	1.0	0.3	0.06	3	5.0
8-9	1.5	0.1	0.07	15	1.4
9-10	1.3	0.2	0.09	7	2.2
10-11	1.0	0.2	0.08	5	2.5
11-12	1.3	0.4	0.07	3	5.7
12-13	1.3	0.4	0.07	3	5.7
13-14	1.4	0.1	0.08	14	1.3
14-15	0.9	0.1	0.08	9	1.3
15-16	1.1	0.3	0.08	4	3.8
16-17	1.1	0.1	0.09	11	1.1
17-18	1.4	0.1	0.08	14	1.3
18-19	1.1	0.2	0.09	6	2.2

(Ehr.) Grunow apud Cleve and Grunow, *Melosira italica* (Ehr.) Kutzing, *Fragilaria crotoensis* Kitton, and *Asterionella formosa* Hassall. These same species were found in the upper sediments of much-studied, eutrophic Linsley Pond in Connecticut (Patrick, 1943). Patrick records that these species are characteristic of and reach their best development in eutrophic waters.

Lake Tahoe, California-Nevada

Lake Tahoe, astride the California-Nevada state line in the Sierra Nevade Mountains, is one of the clearest, deepest freshwater lakes in the world. Situated at an elevation of 6,225 feet, Lake Tahoe is 192 square miles in area (122,880 acres) and has a length of 21.6 miles and a width of 12 miles. The lake's maximum depth is 1,645 feet; its mean depth is 990 feet, and its volume is approximately 122 million acre feet. The 1,200-foot depth contour is often less than a mile from the nearest shore,

Table 12. Diatom Remains in Lake Sebasticook Sediments

Segment core (depth in inches)	Diatom particles (millions per gram)
1-2	326.4
4-5	54.8
5-6	47.4
6-7	45.8
7-8	40.2
8-9	22.3
9-10	7.7
11-12	2.7
18-19	0.1

and never more than three miles. The Tahoe drainage basin is 506 square miles.

At the present time,* the waters of Lake Tahoe are not enriched, nor do they support dense algal populations. Threats of future problems are serious, however. The phosphorus concentration in some near-shore areas is now at a critical level for the stimulation of algal growths, and all of the phosphorus present as shown by analytical tests is available for algal utilization. Available nitrogen concentration is presently low and is believed to be the major nutrient limiting algal development beyond the lake's present capacity. Potentially nuisance-producing blue-green algae and filamentous green algae are now present in some near-shore areas of the lake. Furthermore, the impact of nutrients from inflowing streams on the lake water was demonstrated by increased phosphorus concentrations and, in some cases, increased algal concentrations. Presently, this impact is limited to the near-shore waters surrounding the stream's mouth.

Temperature data indicate that the lake stratifies and that a thermocline occurs at a depth of 50 to 70 feet during summer months. Complete overturn has not been observed but may occur during winters of unusual severity.

Observations have been made on water transparency by viewing a white disc, approximately 8 inches in diameter, as it was lowered in the water. The white disc was observed to a depth of 136 feet at one station on April 4, 1962. This may be compared to a transparency value of 5 feet, or less, in a eutrophic lake with a heavy algal bloom. A minimum transparency of 49 feet, associated with a relatively high concentration of plankton, was observed in Tahoe's Emerald Bay on May 21, 1962. Although transparency measurements have been made on several occasions during the past 90 years by different investigators, no significant long-term trend can be detected.

Two of the major nutrients, nitrogen and phosphorus, are always of interest in connection with lake investigations because of their role in biotic production and in nuisance plant growths. Samples were analyzed from 12 offshore sampling points and 45 near-shore points for nitrate nitrogen (N) and soluble phosphorus (P) during both May and July. Nitrate nitrogen was present in an average concentration of 9.2 μg N/l in May and 8.0 μg N/l in July in the offshore areas, and 6.4 μg N/l during both months at near-shore stations. Concentrations of ammonia nitrogen, nitrite nitrogen and organic nitrogen were below the analytical limits. The average concentration of soluble phosphorus was 5.1 and 10.9 μg P/l in May and July respectively in the offshore areas and 6.1 and 8.7 μg P/l in May and July respectively in the near-shore areas. No significant differ-

* Report on Pollution in the Lake Tahoe Basin, California-Nevada by A. W. West and K. M. Mackenthun in cooperation with the Southwest Regional Office, San Francisco, Calif., U.S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio, July 1966.

ence between concentrations of soluble and total phosphorus was found, indicating that all phosphorus was in the soluble form.

Thirty-nine samples were collected from a depth of about 100 feet for plankton and chlorophyll determinations. Essentially all of the phytoplankton were diatoms. All counts were less than 500 organisms per ml with the exception of some near-shore areas. The Tahoe City boat harbor had 1,260 organisms per ml in April and 3,890 in July; both are considered algal blooms.

At the time that phytoplankton collections were made, water samples were analyzed for chlorophyll. Although chlorophyll *a* concentrations are considered low with a maximum July concentration of 1.74 mg/m ^{3}, areas where chlorophyll *a* concentrations are greatest are located principally around the south and east near-shore (figure 58). Other areas of the lake have values less than 0.3 mg/m ^{3}.

Organisms that are able to attach themselves to the surface of an object were studied by means of microscopic glass slides that were suspended in the lake water at different depths and removed at weekly intervals and examined microscopically. Bacteria outnumbered all other organisms and in some cases were the only organism found.

Although organisms of the type that produce objectionable growths such as filamentous algae, including blue-greens, are already present in near-shore areas, they are not now excessive because of low nutrient concentrations and a resulting low growth rate.

Lake Michigan

In a biological study of Lake Michigan* it was found that massive areas along the perimeter of the southern half of the lake were polluted to such an extent that large populations of pollution-tolerant sludgeworms occurred. The 2,100-square-mile area classified as polluted in figure 59, extending from Chicago northeastward around the southern tip of Lake Michigan, resulted from organic nutrients discharged by the large metropolitan areas bordering the lake. Lake sediments supporting populations of sludgeworms greater than 100 per square foot (approximately 1,000 per square meter) are considered polluted. Other areas with polluted lake bed sediments occurred in Green Bay, adjacent to the shorelines of Manitowoc, Sheboygan, Port Washington to Waukegan, and between Ludington and Manistee. Despite generally higher sludgeworm densities in inshore areas, the average number of organisms was depressed in a narrow band along the Chicago and Indiana shoreline. This was probably a result of wave action in the inshore areas which did not allow the settling of fine organic particles.

The waters of Chicago Harbor, Calumet Harbor and Indiana Harbor each contained excessive amounts of algal-stimulating nutrients. In Chi-

* Lake Michigan Basin Biology, Federal Water Pollution Control Administration, Great Lakes Region, Chicago, Ill., January 1968.

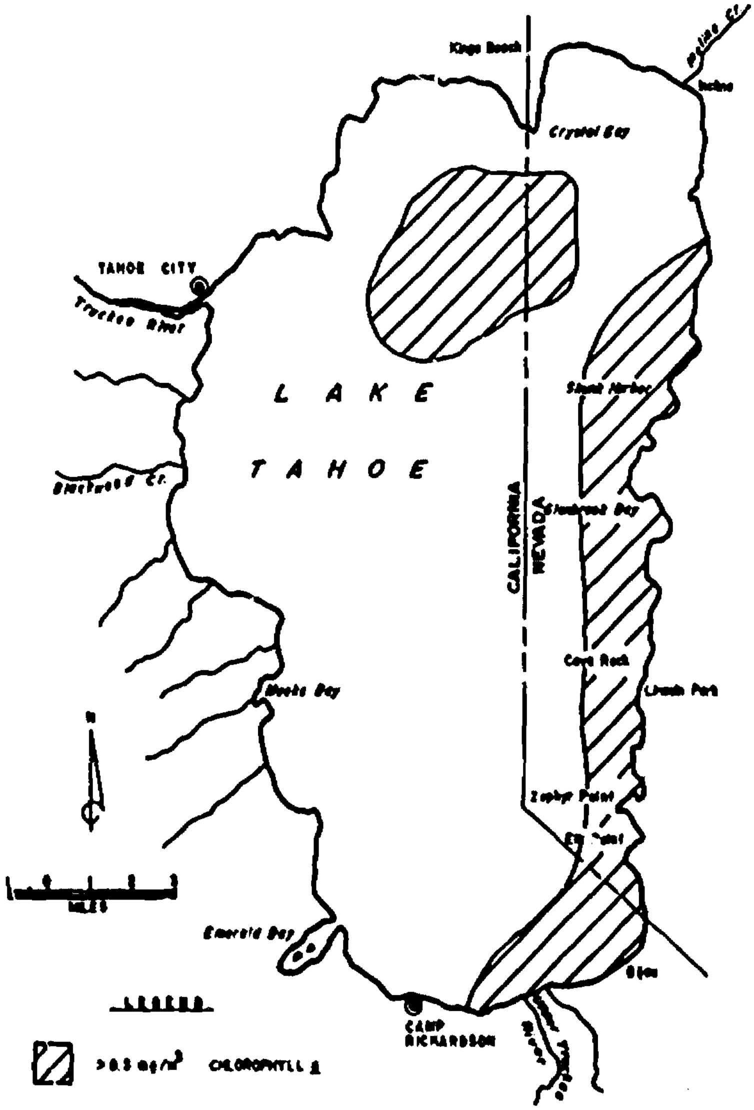

Figure 59. Lake Tahoe chlorophyll a values.

cago Harbor, soluble phosphates (PO_4) averaged 0.04 mg/l and ranged as high as 0.15 mg/l. In Calumet Harbor, soluble phosphates averaged 0.05 mg/l and ranged as high as 0.14 mg/l; total inorganic nitrogen averaged 0.35 mg/l/N and ranged as high as 1.02 mg/l. Indiana Harbor water contained an average of 0.05-mg/l soluble phosphate and ranged as high as 0.12 mg/l. Total inorganic nitrogen averaged 1.56 mg/l and

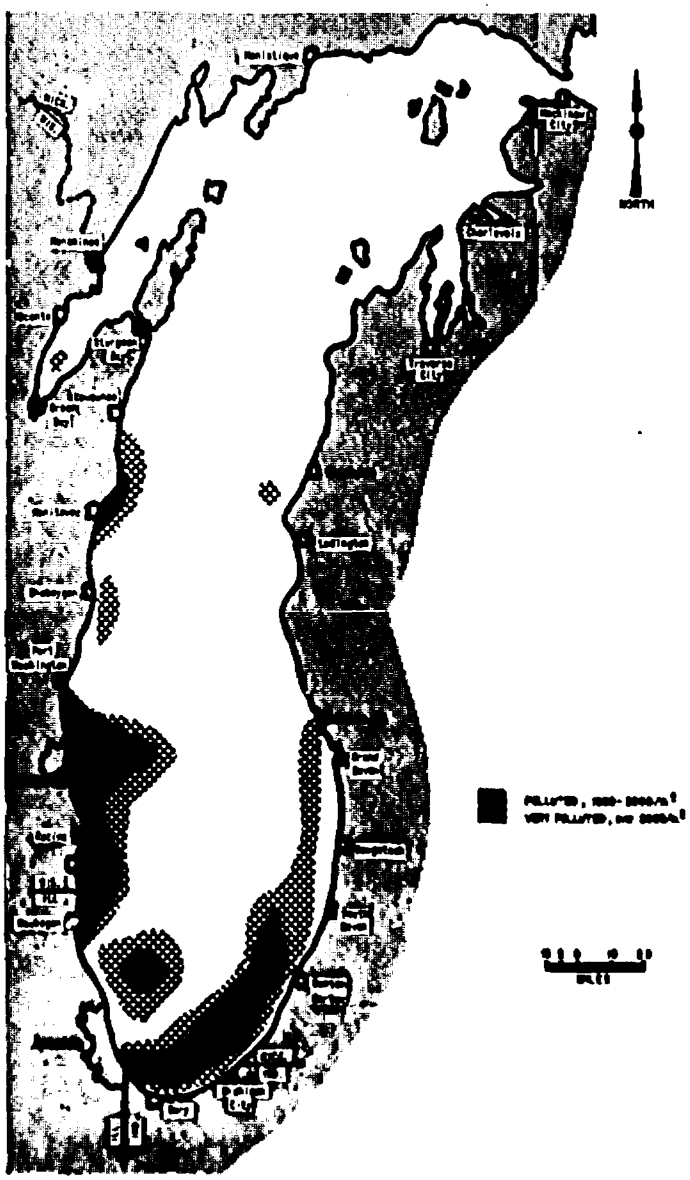

Figure 59. Lake Michigan sludgeworm populations, number per square meter.

ranged as high as 3.14 mg/l. A concentration of 0.30 mg/l inorganic nitrogen is considered critical for stimulation of algal growth in the presence of adequate phosphorus.

Phytoplankton populations in the Chicago-Calumet area remained dense during the period of study. In 1962, up to 1,298 organisms per milliliter were found. In 1963, phytoplankton populations increased to 2,143 phytoplankton organisms per milliliter. Light penetration in the Indiana Harbor Canal was severely restricted; a Secchi disc was not visible at one meter.

The distribution of phytoplankton in Lake Michigan was generally influenced by wind-produced currents. In spring, 1962, over 500 phytoplankton per milliliter were collected from inshore waters, beginning at the Chicago-Calumet area and continuing north up the entire eastern lake shore (fig. 60). By the summer of 1962, the current pattern had changed; phytoplankton distribution became more random, except for high numbers of organisms (over 300 per ml) near Chicago and South Haven. Fall, 1962, phytoplankton counts again revealed high concentrations of over 500 organisms per milliliter along both the southeastern and southwestern shores.

Badfish Creek, Wisconsin

In the early history of Madison, Wis., Lake Monona received its raw sewage and later treated sewage effluent. In 1962, the Nine-Springs sewage-treatment plant was placed in operation and the effluent from this installation was carried via Nine-Springs Creek to the Yahara River upstream from Lakes Waubesa and Kegonsa. The enrichment of these lower Madison lakes by the highly nutritious effluent produced nuisance algal growths, offensive odors, and periodic fish kills. These conditions led to innumerable complaints, much debate, and evenutally legislative and legal action, which forced the diversion of effluent from the Madison Metropolitan Sewage District's Nine-Springs Treatment Plant around the lower Madison lakes.

The route chosen for the diversion of the Nine-Springs effluent necessitated five miles of 54-inch pipeline and nearly 4 miles of open ditch which led southward and entered Badfish Creek. Badfish Creek was straightened and improved to a width of at least 16 feet for 10 of its 14.5 miles of length. The unimproved portion after some meandering, enters the Yahara River downstream from the Madison lakes. Badfish Creek is a small stream that flows through typical oak opening agricultural lands in Dane and Rock Counties. Portions of the stream have had a history of being marginal trout water.

The Nine-Springs Sewage Treatment Plant provided primary and secondary treatment for all wastes from the Madison Metropolitan area of 85 square miles with a population of about 135,000. Flow through the plant averaged about 20 million gallons per day. Primary treatment consisted of screening, grit collection, and sedimentation. About one-fourth of the sewage received secondary treatment by the trickling filter process,

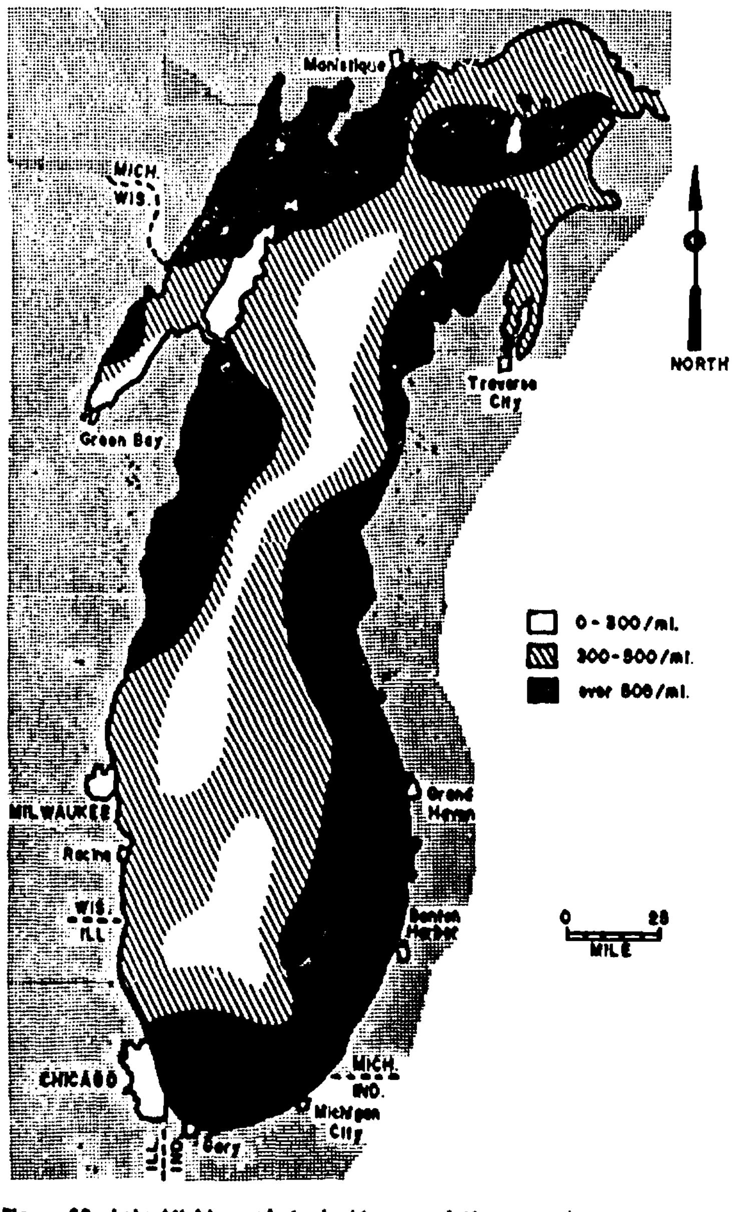

Figure 60. Lake Michigan phytoplankton populations, number per milliliter, Spring, 1962.

and about three-fourths of the sewage received secondary treatment by the activated sludge process. The effluent received chlorination.

As the effluent left the 54" pipeline, it entered a rather straight ditch

with steep banks. The first approximately one-half mile of this ditch often carried a blanket of detergent foam. Approximately one mile farther downstream, the banks of the ditch became less steep, and as early as 1 year following diversion, there was evidence of vegetation encroachment, principally round-stemmed bulrush. Badfish Creek itself was dredged to a bottom width of 16 feet for approximately 4 miles, and a bottom width of 20 feet for the remaining 6 miles of improved stream. Along with the changes wrought by physical disturbance, there was a change in flow produced by the introduction of approximately 20 million gallons per day of effluent. Prior to diversion, Badfish Creek at about its midpoint between its origin and confluence with the Yahara River had an average flow of 9.6 c.f.s. for the 2½ years in which records were kept. Following diversion, the flow averaged 43 c.f.s.

Concurrent with the discharge of quantities of suspended solids, a sludge deposit built up over most of the upstream portions of Badfish Creek (Mackenthun et al., 1960). In some areas, especially in small pockets along the sides of the stream, this deposit approached 6 to 10 inches in depth. In most of the upstream region, as well as the ditch itself, the sludge was of sufficient thickness to produce a suitable habitat for a bountiful population of midge larvae.

Prior to and after diversion, organic nitrogen in Badfish Creek increased from 0.73 to 4.1 mg/l. Soluble phosphorus (P) rose from 0.19 to 5.96 mg/l. Following diversion the streams biochemical oxygen demand was 17.3 mg/l.

The mean phytoplankton volume showed no statistical difference either between stations on a given river or between the two periods of study for the same station. It thus appears that a sizable increase in nutrients in a flowing water situation had no substantial effect upon a volumetric production of phytoplankton.

Organisms that dwell upon and within the bottom deposits were studied at seven separate stations on four different dates in Badfish Creek.

Following diversion, the improved portion of Badfish Creek still maintained a coarse gravel bottom, and in the upstream reaches, the stream was choked with submerged vegetation. In the downstream reaches, this vegetation appeared to be less dense than before diversion. Long streamers of filamentous green algae (*Stigeoclonium* and *Rhizoclonium*), some of which were estimated to be 50 feet in length, were attached to bottom materials at numerous locations. In the upper areas of the stream, there was a green blanket of *Oscillatoria* covering the bottom. Sludge had deposited along the edges of the stream and covered portions of the vegetation. A definite sewage odor was present in upstream reaches in September, and this odor extended the full length of Badfish Creek in December, 1959. Much of the stream bed was covered with a slimy mat of the blue-green algae *Oscillatoria*, and especially in the December survey, much of the vegetation was covered with a prolific growth of a stalked protozoa

belonging to the family *Epistylidae*. These formed a gray mass not unlike a dense growth of fungus.

The degradation of the stream following diversion is apparent when one examines the community of biological life living upon and within the bottom materials. Prior to diversion, between 10 and 14 different invertebrate species were recovered from each of the samples collected. Following diversion, the number of species was reduced to about five.

Prior to diversion, also, a balanced community of intolerant and tolerant organisms were observed. At nearly every station, caddisfly larvae (*Cheumatopsyche* and *Hydropsyche*), mayfly nymphs (*Baetis* and *Caenis*), and riffle beetle larvae were found in association with cranefly larvae, horsefly larvae, scuds, and miscellaneous midges. Very tolerant forms such as sludgeworms (*Tubificidae*) were also found, but occurred in very low numbers. In some locations, the intolerant caddisfly larvae formed most of the total population.

Following diversion, all stations in the ditch and in the improved portion of Badfish Creek supported a bottom-dwelling population comprised of sludgeworms (*Tubificidae*) and at least three species of very tolerant midge larvae (*Tendipes plumosus, T. tendipediformis,* and *T. decorus*). These were all considered to be very tolerant organisms and were found to be living in the sludge deposits on the bottom and along the sides of the stream. Near the lower end of Badfish Creek in the unimproved portion, tolerant and very tolerant bottom-dwelling organisms predominated. Occasionally, an intolerant form was observed, but this was only one among many of the more tolerant forms.

11

MARINE ENVIRONMENTS

San Diego Bay

SAN Diego Bay, a crescent shaped natural water body, has a length approximating 15 miles, a maximum width of 2½ miles and a surface area of about 18.5 square miles. Water depths vary from less than 1 foot in the southern end to 41 feet in the harbor entrance. The bay is surrounded by metropolitan San Diego with a population of over 860,000. The shoreline area, with the exception of a few small sections, has been developed for residential, recreational, military, or industrial uses. A deep-water harbor and extensive docking facilities permit use of the bay for naval activities, maritime commerce, industrial use, research, aesthetic enjoyment and recreation. Varied forms of practiced recreation include boating, fishing, swimming, water skiing, and wading.

There is no dilution of San Diego Bay by freshwater in summer and salinities range from 33 to 34 parts per thousand (p.p.t.) over the entire year except in the south end of the bay where evaporation may increase salinities to 35 or more p.p.t. Average water temperature varies from a high of about 26° C. during late summer to a low of 14–16° C. during winter.

Prior to 1963, municipal and industrial wastes from the metropolitan areas were discharged to the bay. Since the completion of an off-shore ocean outfall, wastes now entering the bay are minimal. The objective of the biological survey from October 8 to 28, 1967, was to assess the effects of pollution from ships and industries on San Diego Bay* biota.

San Diego Bay was divided into South Bay, Central Bay, and North Bay and 59 sampling stations were selected to depict aquatic life (fig. 61). A Petersen dredge was used to collect bottom-associated organisms. After a bottom sample was collected with the dredge, it was placed in a

* San Diego Bay. An Evaluation of the Benthic Environment. L. P. Parrish and K. M. Mackenthun, Technical Advisory and Investigations Branch, Federal Water Pollution Control Administration, 5555 Ridge Avenue, Cincinnati, Ohio, 1968.

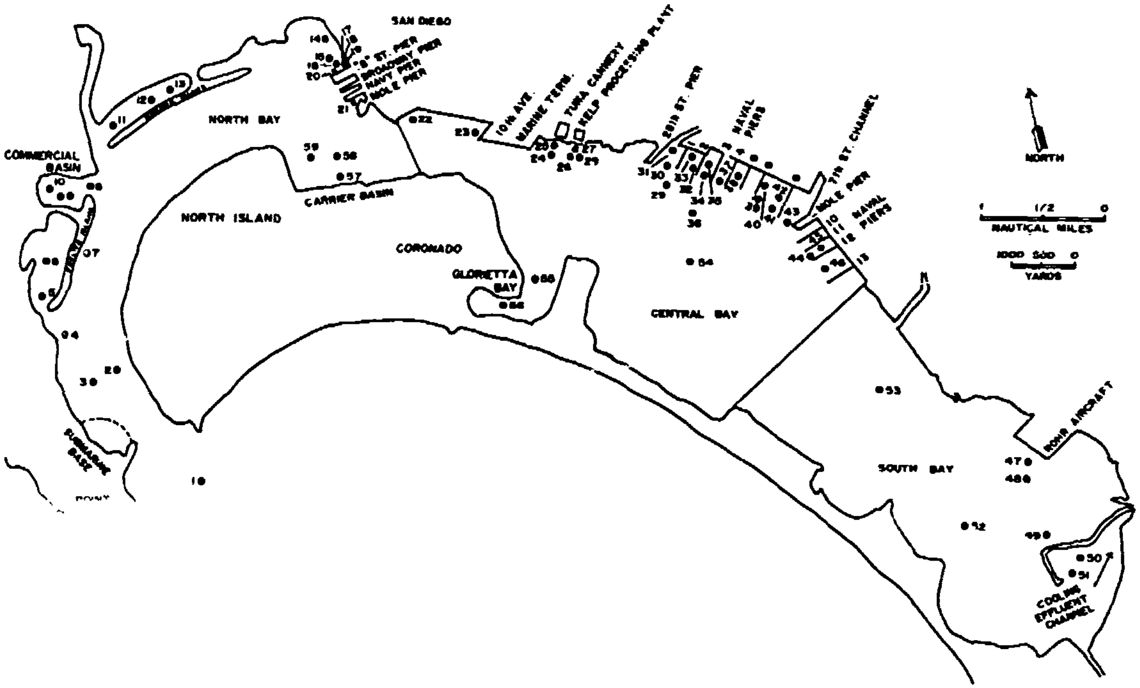

Figure 61. Sampling stations on San Diego Bay, Calif., October 1967

small tub. Water was added and the sample was mixed to a slurry and strained through a U.S. Standard No. 30 sieve. The organisms and coarse debris were removed from the sieve and preserved for later examination.

To determine the extent and condition of sludge deposits, core samples were collected with a Phleger type coring device. Sludge depths were determined by measuring the length of penetration of the coring device, evident as a smear of sludge or mud on the outside of the tube, and the length of core collected. Core length was divided into the length of penetration to obtain a multiplication factor for the amount of compaction. This factor multiplied by the length of sludge-like material in the core equalled the assumed sludge depth.

South Bay was affected only slightly by pollution. In six of eight areas sampled, there were at least seven species of organisms and as many as 13 species in the sandy bottom at station 53. The most evident pollution was in the cooling effluent channel from a steam electric plant where the rocky bottom was covered with black sludge and filamentous algae (station 50). A water temperature of 88° F. was recorded here at the time of sampling. Floating mats of dead algae were evident and materials from the bottom had a distinct hydrogen sulfide odor. Polychaete worms numbered 1,400 per square foot, denoting a polluted area; only two kinds of other organisms were found in this channel, a pollution-tolerant snail being the more numerous. The channel contained 25 inches of organic sludge with 2.3 percent organic carbon and 0.16 percent nitrogen, indicative of organic debris. These sludges developed because of the rapid growth, die-off and deposition of plants and animals in the heated effluent.

In contrast, on the opposite side of a jetty separating the effluent channel from the bay (station 49), 188 polychaetes per square foot and seven kinds of adidtional organisms indicated a cooler and unpolluted environment. A gray mud and sand mixture contained 1.6 percent organic carbon and 0.16 percent organic nitrogen.

Central Bay was the most polluted. Near the center of the bay, station 54 indicated slight pollution only and supported 9 kinds of animals. Near San Diego's shore, many stations supported only polychaete worms and these ranged from 10 to 1,300 per square foot depending upon the degree of inhibitory toxins within the sludge. Severe organic pollution resulted in very low numbers of polychaetes with no other kinds of organisms. Other stations supported 1 to 3 organisms in numbers that seldom exceeded 6 per square foot in addition to the polychaete worms.

Sludge extended outward from shore to the area of the pierhead line. Within this area a gradation from active sludge inshore to a more stable sludge in the pierhead area was found. Sludge depth was determined to be 44 inches at one station and to exceed 30 inches at 9 of 16 station measurements in this area. Organic carbon varied from 2.2 to 9.9 percent and organic nitrogen from 0.14 to 0.91 percent. Comparing these data to

those presented in table 7, much of the sludge was indicated to be fresh and actively decomposing.

North Bay had localized areas of pollution. Close to shore in the Carrier Basin, only polychaetes numbering 190 per square foot were found. Approximately 600 yards from shore, bottom materials had stabilized enough to support 40 polychaetes and 30 molluscs of one species per square foot. Over 30 inches of stable sludge with 2.0 to 2.2 percent organic carbon covered the moderately polluted bottom. Before 1963, the sewage outfall for the city of Coronado was located just east of the basin. Since the basin exceeds 40 feet in depth with little circulation, a sludge buildup resulted. Settleable solids discharged from carriers docked in the basin would also contribute to the sludge bed.

Across the bay, at the junction of B Street pier and the shoreline, a storm sewer outfall discharged organic wastes and other debris from the San Diego Zoo. Samples of the bottom within an approximately 40,000-square-foot area surrounding the outfall contained oil and black sludge that emitted hydrogen sulfide odors. The area supported 100 to 1,200 polychaetes per square foot and other pollution-tolerant organisms.

Inside Harbor Island (station 12), 6,500 polychaete worms per square foot were the only organisms found, in contrast to 90 worms per square foot and 8 kinds of organisms at station 13. Sand had been dredged from the area near station 12. A depression in the bottom had collected organic debris from the surrounding sand when it was redistributed, and provided an organically polluted substrate resulting from dredging.

Many polychaete worms, 3,400 per square foot, were found at the entrance to the Commercial Basin. Bottom materials were primarily sand. Halfway between the entrance and the end of the basin, a population of 2,000 polychaetes per square foot were found in a sand and clay mixture. Three-fourths of the distance into the basin, a soft, black-decayed sludge supported 200 polychaetes per square foot and three other kinds of organisms including pollution-tolerant snails and crabs. Suspended organic materials discharged from vessels docked in the area. and in water entering the bay, settled out of the slow moving water near the end of the basin. The large number of polychaete worms in the basin indicated moderate pollution.

Within North Bay, organic carbon within bottom sediments was not found to exceed 2.2 percent and organic nitrogen did not exceed 0.18 percent, which indicated generally stable sludges or organic silts and loam.

Analysis of all benthic data from San Diego Bay indicated that a finding of less than 5 kinds of organisms or more than 200 polychaete worms per square foot represented a polluted environment. Among all stations, the organisms per square foot varied from 13 to 6,400 and polychaetes made up 44 to 100 percent of the total numbers. Polychaete worms were

found at all stations. Other organisms were found at 75 percent of the stations, and at 2 stations in South Bay the number of organism kinds reached 12 and 13.

Charleston Harbor, South Carolina

Samples of bottom-associated life, collected during September 20–24, 1965, revealed adverse conditions for benthos in several reaches of the Charleston Harbor estuary.*

In the lower reaches of the Ashley River (fig. 62), pollution was evident from the vicinity of Highway No. 7 downstream to the river's mouth. Midchannel benthic environments lacked bottom-associated organisms. Deposits in the channel near particular outfalls were comprised of dark-colored muds and oily substances that emitted odors similar to those of petroleum. Bioassays conducted with such deposits on certain snails, shrimps, and fish demonstrated that these muds were toxic to the organisms tested. Bottom deposits in downstream reaches to the mouth of the river consisted of black muds and organic matter, and produced foul odors like those of domestic sewage.

The lower reaches of the Cooper River contained significant discharges of wastes from upstream sources. Pollution was evident in the Cooper River in reaches immediately upstream and downstream from Buoy 60. Sludge deposits were abundant, and bottom associated organisms were not found. Marine worms were found in benthic environments both upstream and downstream from these grossly polluted reaches. Partial recovery was indicated near the mouth of the Cooper River where oysters and 7 other kinds of animals were found; however, certain clean-water associated forms such as shrimps and crabs were absent.

The Wando River was not discernibly polluted. Benthic reaches of this river were composed of hard clays mixed with scraps of shells and vegetation, and provided conditions suitable for 3 kinds of clean-water associated shrimp.

Moderately polluted areas were apparent in the main harbor from the mouths of the Ashley, Cooper, and Wando Rivers seaward to near Fort Sumter. Benthic environments in these reaches supported only marine worms. Bottom deposits were either black mud or black muds mixed with bits of shells, clay, or sand. Deposits consisting only of black mud were found in the reach south of Shutes Folly Island near the mouth of the Cooper River, and in the reach west of Shutes Folly Island; these muds emitted petroleum-like odors comparable to those associated with deposits in the lowermost reaches of the Ashley River.

* A report on the water quality of Charleston Harbor and the effects thereon of the proposed Cooper River rediversion. Federal Water Pollution Control Administration, Southeast Water Laboratory, Charleston Harbor-Cooper River Project, Charleston, S.C. 1966.

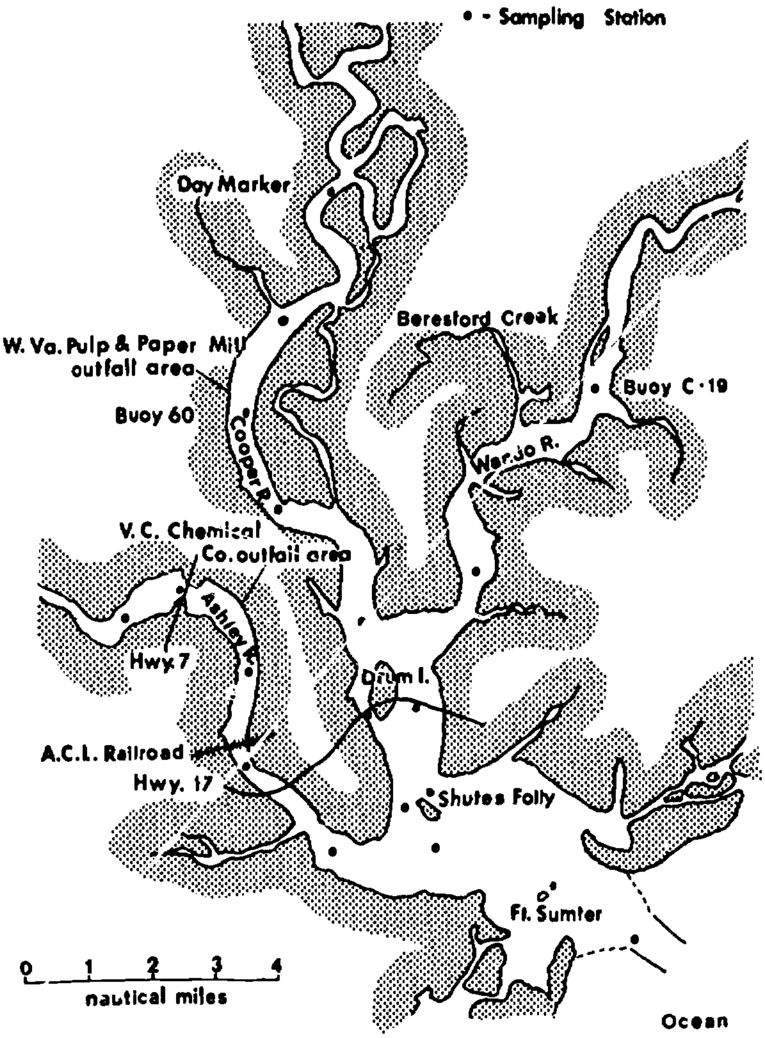

Figure 62. Biological sampling stations, Charleston Harbor 1965.

Benthic environments near Fort Sumter and seaward were not perceptibly polluted. Such environments were suitable for clean-water associated shrimp, and clams or crabs. Phytoplankton tended to be more abundant than 3.5 p.p.m. in reaches inland from Shutes Folly Island, and was less than 3.5-p.p.m. seaward from Shutes Folly Island. This distribution of phytoplankton was apparently associated with estuarine enrichment induced by waste discharges. Counts as numbers per ml. never exceeded 5,000.

Boston Harbor, Massachusetts

Boston Harbor, one of the most heavily used harbors on the Atlantic coast, is a major natural economic asset of Massachusetts. It is a watercourse that bridges the Atlantic Ocean to the Massachusetts coastline, serves both commercial and military navigation, provides berthage, protects from heavy seas, provides recreation, produces food, and assimilates untreated and partly treated sewage from 2.5 million people plus industrial wastes from the Boston metropolitan area. Wastes from an additional 0.4 million people and several industries are added to Boston Harbor or its tributaries from sources adjacent to the metropolitan area.

Boston Harbor has an area of approximately 44 square miles (28,000 acres), with depths ranging generally between 10 and 50 feet at mean low tide. Extensive areas of the bay are less than 15 feet deep. Large-craft navigation channels are dredged to maintain minimal depths of 30 feet, and small-craft channels are maintained at a minimum depth near 12 feet. Hydraulic and salinity features of the harbor are controlled chiefly by tides and, to a much lesser extent, by fresh water discharges from tributaries. The relatively small discharge of fresh water coupled with other hydraulic features precluded development of a salt-wedge water mass, and facilitated a vertically mixed type of estuary having more affinities with embayments than estuaries and aquatic life that was marine rather than estuarine.

Seven tributaries in addition to the Charles River drain into Boston Harbor. Only four, the Malden, Mystic, Charles, and Neponset Rivers, discharge significant amounts of fresh water. The Chelsea, Weymouth Back, Weymouth Fore, and Weir Rivers are tidal streams comprised mostly of saline harbor water. During periods of low precipitation, the tributary fresh water discharges to Boston Harbor were near 100 cubic feet per second (c.f.s.) and the discharge of sewage and industrial wastes exceeded 400 c.f.s. The total discharge of fresh waters during these periods did not drastically modify the salinity of the harbor. Except for mouths of tributaries, salinity values in all harbor reaches during periods of low precipitation were greater than 25 parts per thousand. Biological studies of Boston Harbor and its tributaries were conducted to assay water quality and its effect on aquatic life.*

The Charles River is the principal tributary to Boston Harbor. Numerous waste sources from combined sewers severely polluted this stream in reaches used intensively for recreation near its mouth. Only one kind of organism was found at mile 4.0, and none was found at mile 0.6 near the Longfellow Bridge. The paucity of organisms suggested that toxic conditions prevailed, thereby precluding establishment of bottom-associated an-

* Biological Aspects of Water Quality Charles River and Boston Harbor, Mass. R. K. Stewart, Federal Water Pollution Control Administration, Technical Advisory and Investigations Branch, 5555 Ridge Avenue, Cincinnati, Ohio, 1968.

imal life. Black oozy muds that emitted foul odors and contained oily residues were found here, and the surface of the river was pock-marked with bursting gas bubbles. The many combined sewers discharged highly carbonaceous and nitrogenous wastes. The organic carbon content of sludges near the river's mouth was 13.7 percent and organic nitrogen was 0.70 percent. The waters contained 940 $\mu g/l$ inorganic nitrogen (N), 270 $\mu g/l$ total phosphorus (P), and 180 $\mu g/l$ soluble phosphorus. Phytoplankton populations exceeded 10,000 cells per ml.

In addition to the Charles River, certain other tributaries contributed polluted water to Boston Harbor. The Mystic River at the Route 16 bridge near Medford, Mass (fig. 63), supported only one kind of bottom animal. Substantial quantities of oily residues were observed in the black sludge that covered the river bottom. Additional qualitative sampling disclosed that black sludge deposits predominated in the benthic environment of the Mystic River to its confluence with the Malden River. Phytoplankton density in surface waters was high, exceeding 40 p.p.m., or 29,000 cells per milliliter.

The Malden River was severely polluted upstream from its confluence

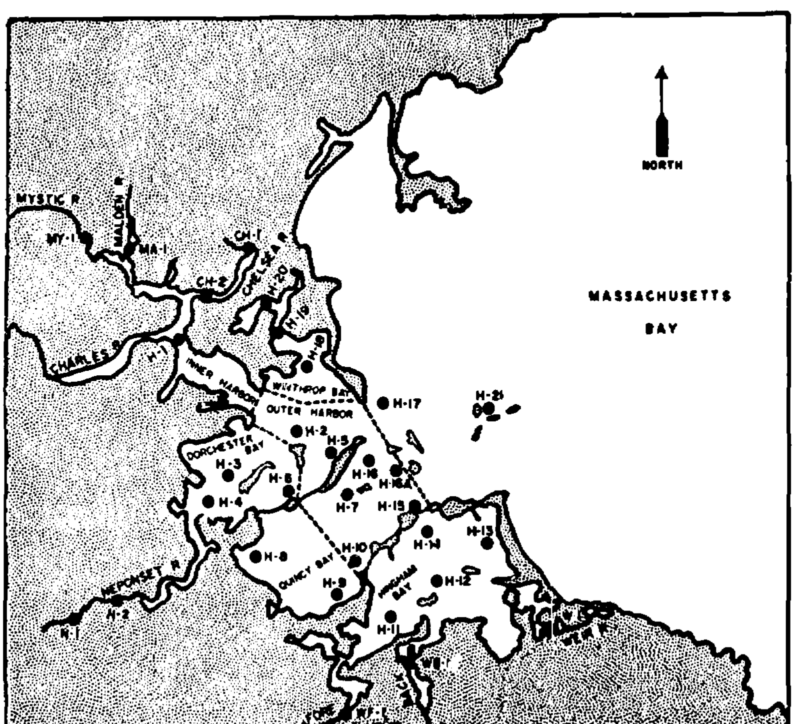

Figure 63. Station locations in Boston Harbor and tributaries.

with the Mystic River. Bottom-associated animals were not found, and 4 inches of black sludge mixed with oily residues covered the stream bottom. Surface waters contained more than 60,000 phytoplankton per milliliter that amounted to a density of 13.8 p.p.m. The Malden and Mystic Rivers contributed severely polluted waters to the inner reaches of Boston Harbor.

Marine waters supporting polychaete worms prevailed in all but one of the remaining tributaries and in all Boston Harbor reaches. Polychaete worms were sufficiently common in these waters that their abundance was used to show areas and degrees of over-enrichment. The use of marine worms for these purposes is not unlike the use of sludgeworms to delineate areas of over-enrichment in fresh waters because the nutritional and substrate requirements of both groups of organisms are similar. Polychaete worm populations that exceeded a density of 200 per square foot in the marine waters of Boston Harbor were considered indicative of excessive enrichment (fig. 64).

The confluence of the Chelsea, Mystic, and Charles Rivers forms Bos-

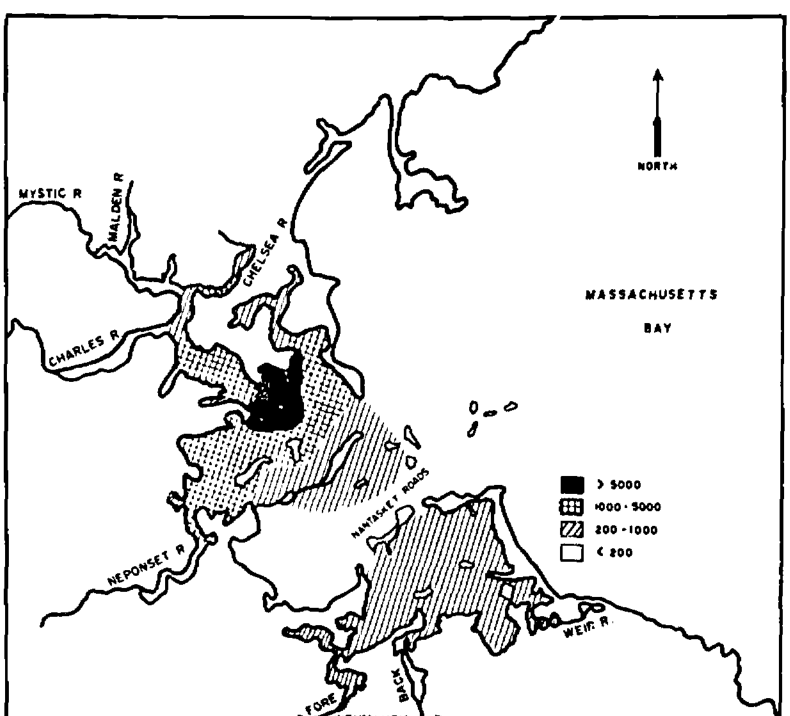

Figure 64. Number of polychaete worms per square foot, Boston Harbor and tributaries, July–August 1967.